

AUGUST 1950

# Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS



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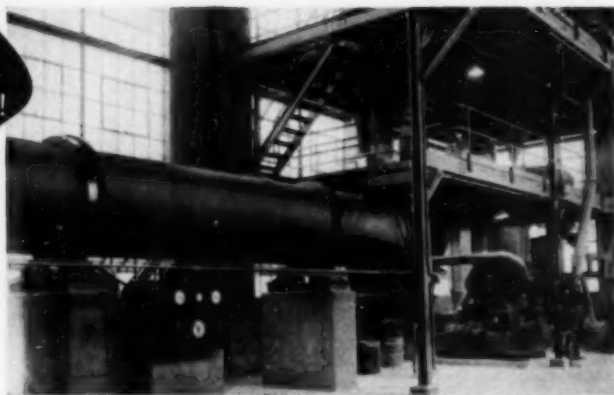
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We liked the remark of Professor Boomsliet of West Virginia University in a recent talk printed in the Journal of Engineering Education. Said the professor: "Once when I was working as an undergraduate for the college carpenter at Michigan State College, I tried to finish a piece with a pocket knife instead of using a wood plane. He caught me at it, and after a few well-chosen remarks he said, 'You can noddings do unless you have somethings to do mit!'"

E.J.C. (Engineers Joint Council) through Task Committee just finished a huge report on the nation's water policy. The complete report, news of it is on page 14, contains a lot of interesting facts—for instance, the public water supply requirements for the entire U. S. are only 10% of the flow in the Niagara River outlet from the Great Lakes. Has info, too, on water usage by industry—gallon per unit product.

The first part of a 21-page article on mixing and agitation is begun in this issue. The paper was written by J. H. Rushton of the Illinois Institute of Technology as a research program for the Mixing Equipment Co. Though the conclusions are in the last part of the article slated for September, the installment here gives history, similitude mechanics and a portion of the experimental work.

Some interesting developments came out of the July 7 Council meeting. See Secretary's Report this month. Note also the suggestions from Local Sections for A.I.Ch.E. Directors for the 1951-53 period. Nominating ballots will be mailed from the Secretary's office Sept. 1.

The big problem on C.E.P. is compression—how to compress all we have to publish into the pages the budget allows. For instance this month (aside from publishing only half of Hank Rushton's article) we had to cut down the biggest book review we ever received—on G. G. Brown's "Unit Operations." Even so it ran two and two-third pages. Incidentally Wiley will not have the book finished until late this month. Our reviewers had to work from page proofs. The review starts on page 18.

Volume 46

Number 8

# Chemical Engineering Progress

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1950

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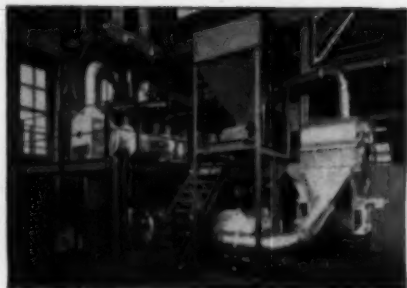
Editor: F. J. Van Antwerpen • Publication Board: W. L. McCabe, Chairman; T. H. Chilton, C. R. De Long, S. L. Tyler, F. J. Curtis • Publication Committee: T. H. Chilton, Chairman; W. I. Burt, W. E. Lobo, M. C. Molstad, J. H. Perry, M. C. Rogers, K. M. Watson, Ex-officio; G. E. Holbrook, F. J. VanAntwerpen • Advertising Manager, Lansing T. Dupree.

Published monthly by American Institute of Chemical Engineers, at 15 North Seventh Street, Philadelphia 6, Pennsylvania. Editorial and Advertising Offices, 150 East 41st Street, New York 17, N. Y. Articles for publication, and communications regarding the editorial content for Chemical Engineering Progress, should be sent to the Editor at the Editorial Office. Statements and opinions given in articles and editorials appearing in Chemical Engineering Progress are those of the contributors, and the American Institute of Chemical Engineers assumes no responsibility for them. Subscriptions: U. S. and possessions, \$6.00; Canada, \$6.50; Pan-American Union, \$7.50; Other Foreign, \$8.00. Single copies of Chemical Engineering Progress older than one year cost \$1.00 a copy; others are 75 cents. Entered as second class matter December 9, 1946, at the Post Office at Philadelphia, Pennsylvania, under the Act of August 24, 1912. Copyright 1950 by American Institute of Chemical Engineers. Member of Audit Bureau of Circulation. Chemical Engineering Progress is indexed regularly by Engineering Index, Incorporated.

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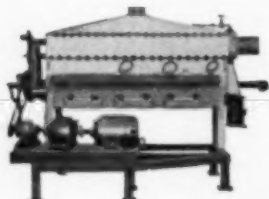
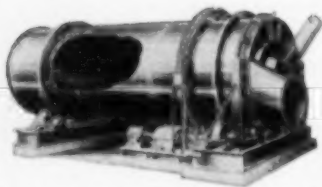
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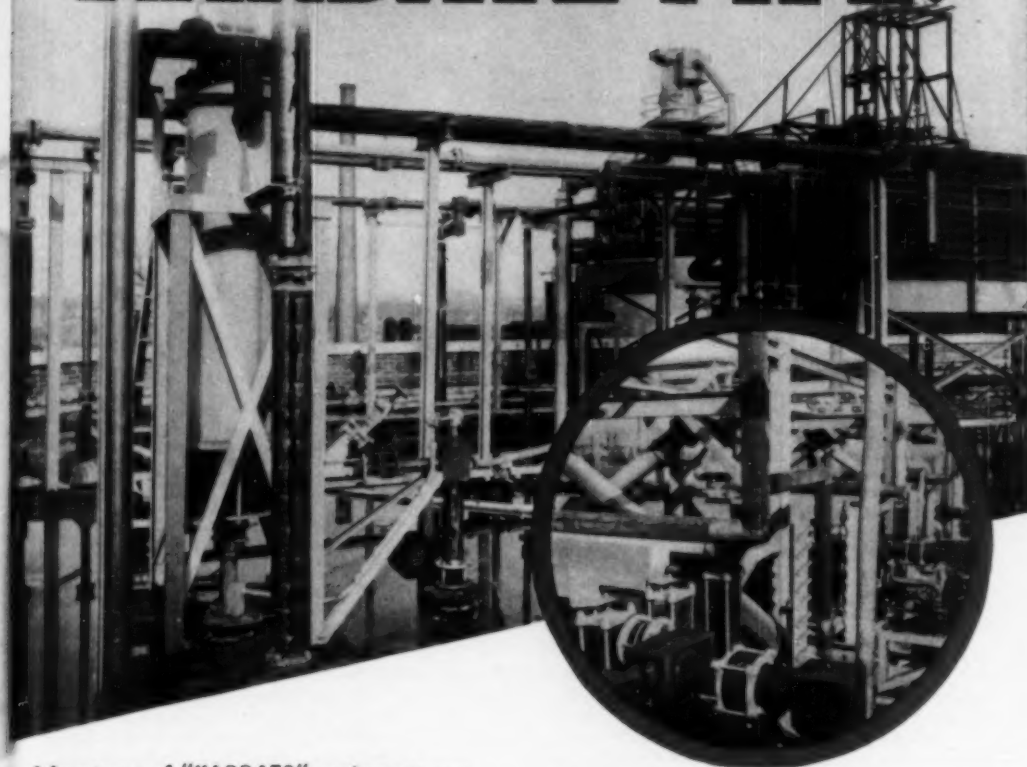
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# OPINION AND COMMENT

## LET THE HUMANIST MEET THE ENGINEER

**I**N recent years there has been considerable criticism of the engineer and scientist for not having played a more conspicuous part in the political and social affairs of modern society. It is tacitly assumed that this is the fault of the scientist, and further, that something is lacking in the science and engineering curricula which leads to this state of affairs.

I believe considerable evidence could be assembled to cast doubt on the allegations that scientists and engineers are not active in civic affairs—particularly at the local levels. We all can name persons with scientific training who are active in municipal affairs, and I have no fear that the graduates of our universities and technical schools will not continue to do so. I doubt that it is deplorable that “of 531 members of Congress there are six engineers, . . . 299 were lawyers.” Is not the legal profession primarily concerned with our political and social institutions? We should feel encouraged that there are so many men trained in the sciences who are active in governmental affairs, despite the fact that they are not in their major field, and that few appreciate the type of contribution they can make. And at that these older men have not had the advantages of recent efforts to humanize and liberalize collegiate curricula in engineering.

However, there is no particular evidence that an increase in the humanistic studies in the science curricula will arouse the social consciousness of the scientist and engineer. Surely there are men in legal and religious work who are as astute and able mentally as the engineer, and they are experiencing difficulty in solving our social problems even though their collegiate experience has been exclusively in the realm of the liberal studies and humanities. The complete answer is not that the engineer needs more exposure to the humanities; the humanist could be made more conscious of the basic philosophies of the sciences.

Perhaps what is needed is an improved cross-fertilization of ideas between the humanities and engineering. All credit to the engineers for realizing that they should be more aware of society and its moral, ethical, and political needs, but this is only a part of our present problem; actually it is a minor matter in our over-all educational responsibility. It is also of great importance that courses be provided in the liberal studies, journalism, law, economics, and religious curricula to introduce science and engineering philosophy to these areas. Students in these fields are primarily concerned with the humanistic phases of our society. Is not this the group who should be made aware of the capabilities and fields of interest of our scientists and engineers? The scientist is concerned primarily with what makes things work; the engineer in how to assure the occurrence of a desired result. It is to

acquaint the non-engineer with this philosophy that should be our object. How can we as engineers expect to influence the thinking of our legalists by competing with them in their specialties? The reverse would not seem to be reasonable. Therefore, why not broaden the educational experience of the embryo lawyer or governmental specialist. We need have no fear of being left out of the councils of our political and social thinkers if they appreciate properly our own special scientific fields, and can be shown how engineering thinking must be integrated with social thinking.

We have passed through an era in engineering education wherein the importance of liberal studies has been emphasized. Some feel that we have overemphasized this desirable discipline. It is time to consider reversing the process to provide engineering experience for the non-engineer. Studies on the philosophy of and the potential impact of the work of the engineer on society, given from the viewpoint of the engineer, must be introduced in our liberal curricula before we may expect many men in public affairs to be aware of the interaction of science and humanity. When they do, better prospects will exist for cooperation between all groups of our society.

Engineering education is young. It will mature in proportion to the way it develops a philosophy and makes that philosophy known and felt by our community. We need men who will take time to interpret the capabilities and limitations of the engineer with respect to other components of society. I hope someday we may see a professor of engineering giving lectures to students in liberal curricula and explaining the philosophy of science and the possible interrelations of engineering and our social order.

As chemical engineers we realize how adaptable and elastic our process industries can be. We must be aware of the social and political implications of our acts, and how the acts of government put new boundaries on our thoughts. I plead for an equivalent understanding by the non-engineer, so that he may be in better position to integrate his thoughts and acts with those of the engineer. We now lack a large measure of cooperation in our daily social problems, not alone because the engineer may not be a good enough humanist, but also because the humanist is not well acquainted with the scientist. Let us mature to the point where we will tell the non-technical men of our work; it is an important and interest-absorbing story. It is not the story of the popular press; it is a story with deep moral and social significance. It should be told by engineers to non-engineers. It should be done at the university during the students' formative years, and it should also be done later whenever the engineer has the opportunity.

*J. Henry Rushton*

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PLASTICS & SYNTHETICS DIVISION

In the July issue *Chemical Engineering Progress* published three papers contributed to the Waste Disposal Symposium at the Pittsburgh meeting. . . . In this issue the Symposium is concluded with the publication of three more papers . . . the first explains how one chemical plant solved its aerial pollution problem . . . another concerns the treatment and utilization of beet sugar process waters and the third tells of a stream pollution abatement program for organic chemical wastes. . . .

# WASTE DISPOSAL

## A CHEMICAL PLANT'S SOLUTION OF AERIAL POLLUTION AND WASTE DISPOSAL

FRED LORENTZ

Hoffmann-La Roche, Inc., Nutley, New Jersey

THE purpose of this paper is to describe the manner in which one chemical plant, manufacturing a multitude of pharmaceutical compounds and their intermediates, is solving its waste disposal problems.

The Nutley (N.J.) plant of Hoffmann-La Roche is spaciouly arranged in a residential community of about 25,000 people. Since 1938, there has been a rapid expansion of production, and the institution of new processes, notably the synthesis of vitamin B<sub>1</sub>, which have given rise to many waste disposal problems, requiring integration and adequate control.

All waste disposal is handled through three channels:

1. Adsorption of obnoxious gaseous wastes at their source
2. Incineration of all objectionable liquid and solid wastes
3. Neutralization of acid wastes and pH control of all water discharged to the public sanitary sewers

**Aerial Pollution Control.** The principal potential aerial pollution offense arises from a few steps in the vitamin B<sub>1</sub> synthesis where the production and handling of sodium dithioformate is involved. The vapors have a tenacious garlic-sulfide stench, as do mercaptans and

hydrogen sulfide which in traces in the air, will adhere to skin and clothing of anyone walking through the operational area, making him conscious of the odor for hours afterward. This smell, uncontrolled, can be readily carried by the wind for several miles, and can be the source of numerous complaints from the residential neighbors. Experiments were made to determine the best method of

adsorbing these odors. The only method which proved satisfactory was the use of activated carbon filters. This is rather an expensive method because the carbon cannot be regenerated in the usual manner with low-pressure steam since it requires regeneration temperatures of 1000 to 1100° F. to liberate the adsorbed material. Hot flue gases are available but the concentrated smell thus liberated reintroduces the original problem of the ultimate destruction of the odorous material. Our procedure is to ship the spent carbon laden with fumes in sealed containers to the suppliers of the activated carbon. These people reactivate the returned material, reclaiming about three quarters of the original charge. The cost of reactivation make-up with fresh carbon and shipping charges is about \$600 every six months. This cost includes the labor charge for replacing the spent canisters with a complete set of spares at a time when a shutdown of

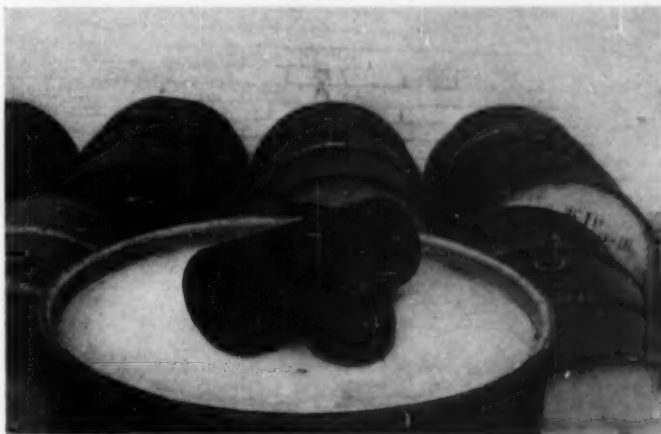


Fig. 1. A Dorex Charcoal Canister



about 6 hrs. will not inconvenience this process operation.

This odor adsorption system consists of a low speed exhaust fan drawing 12,000 cu.ft./min. of air at  $\frac{3}{4}$  in. s.p. through a manifold duct system connected to the vents of about 15 pieces of equipment, all handling the malodorous intermediates. Additional inlets in the duct work draw air from the general area of the building housing this process and the entire mass is discharged through air-conditioning-type dust filters (total cross section about 33 sq.ft.) followed by the distribution plate bearing 503 Dorex-type 42 carbon canisters. The resistance of the canisters is 0.14 in. of water with an air flow of 24 cu. ft./min./unit. The total weight of fresh carbon used is approximately 800 lb. and it will pick up between 300 to 400 lb. of air-borne material including moisture and traces of organic solvents in the six-month cycle. The air stream leaving this adsorption system is entirely free of the objectionable odor. The other air-borne contaminants generated in the chemical operations of other processes are easily scrubbed from the exhaust streams and present no difficult problem. Hydrogen sulfide, hydrogen chloride, nitrous oxide and similar common air contaminants are controlled by scrubbing with caustic solution.

**Incineration of Liquid and Solid Wastes.** There are considerable volumes of waste liquor generated by the various processes at Roche particularly from the vitamin B<sub>12</sub> synthesis, the disposal of which presented a formidable problem. About 1000 gal. of fairly concentrated alkaline waste liquor having a heavy slench of the type previously described must be disposed of daily. Chemical oxidation of this odorous fraction with bleach does not destroy satisfactorily the odor. If this solution were run to the sanitary sewers, the persistent odor escaping from the sewer vents along the way would provoke the populace to complain bitterly. Added to the problem of disposal was a variety of other liquid wastes, some combustible and all not suitable for direct drainage to the sewer. Nichols Engineering & Research Corp. of New York was engaged to design and supervise the erection of a modified Hiler garage incinerator.

Essentially it is a large rectangular combustion chamber connected to a natural draft stack about 100 ft. high. Waste liquor is pumped from underground holding tanks through two solid nickel spray jets from opposite sides of the combustion chamber which is maintained automatically at a temperature of 1100 to 1200° F. The temperature is maintained by two gas flames burning 40 cu.ft./min. of 530 B.t.u. fuel. An

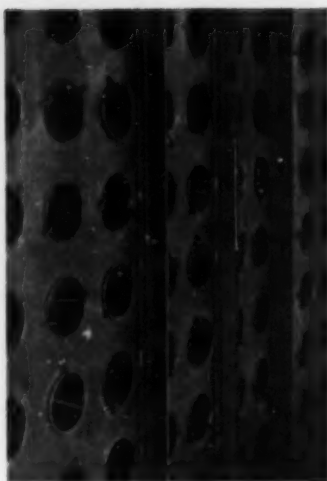


Fig. 2. A Bank of Charcoal Canisters

additional source of heat comes from a steam-atomized oil jet burning No. 2 oil. This oil jet cuts in automatically if the temperature in the chamber drops below 900° F. and will shut off at about 1000° F. Solid waste in the form of paper, wood and other combustible or obnoxious waste is manually fed to the combustion chamber through a trap door from an overhead loading floor convenient to the refuse trucks. Automatic controls cut the gas from full burning to pilot flames when the temperature exceeds 1300° F. due to rapid burning of combustible wastes. It has been found necessary to maintain the temperature in the combustion chamber above 1000° F. to insure complete destruction of all odors. Operating this unit about 6 hours a day, 6 days a week, approximately 24,000 gal. of aqueous material is flash-evaporated and burned along with about 140 tons of solid waste in a typical month. The amount of residue removed from the ash pits of the incinerator is small and is carted away to the public dumps along with other acceptable refuse. Over-all burning characteristics studied at several intervals indicate that about 70% excess air is used and the air flow through the stack is about 1800 cu.ft./min. at 0.2 in. H<sub>2</sub>O draft and the discharge is entirely free of visible smoke.

Controls on this equipment consist of volume indicators on the waste-liquor-holding tanks and the fuel-oil reservoir. Thermal sensitive elements in the combustion chamber and stack indicate temperatures and automatically regulate gas and oil jets.

Noteworthy features in the construction of the incinerator include the pur-

posely weakened arch in the roof of the combustion chamber which will harmlessly fly apart in the event of explosive pressures developing in the furnace. Although there is a pair of explosion-opening doors on the combustion chamber, the light, loosely assembled arch is an added safety feature which proved valuable on one occasion. There is a heavy wire cage enclosing the arch to catch the flying brick in the event of an explosion. Regarding general furnace construction it has been found that ordinary hard-surfaced furnace wall brick will resist the high velocity abrasion of the furnace gases and the thermal shocks of daily shutdowns better than many more expensive materials tested. The two-level grading around the incinerator building makes it convenient for unloading solid waste to the feed chute and removing waste ash at the lower level near the ash pit.

**Effluent Water Control.** The final aspect of waste disposal control is concerned with the treatment of water discharged to the public sanitary sewer. In addition to the usual sanitary wastes common to all disposal installations there is the problem of preparing the chemical waste solutions so that they will be acceptable to the sewerage commission. This means that the plant discharge cannot be acid in pH and must be reasonably free of noxious odor.

In principle, the method of sewerage treatment is simple. Application of lime to the effluent will maintain the pH above 7, and the liberation of odors is least likely from an alkaline waste. It has taken several years and much serious study to develop equipment and techniques to handle the fluctuating pattern of the water wastes of our plant. A treatment station has just been completed incorporating much of this experience.

All branches of the plant system converge into a 30-in. main entering the liming station. The water flows into large acid-brick-lined chambers where it is mixed with a stream of lime slurry, should the pH of the sewage call for it. In this treated form, it flows to the public sanitary system. The lime station processes about 6,000,000 gal. of water a day. Recording pH instruments on this installation sample the flow at the entrance and exit of the liming station as a check on the automatic control system regulating the flow of lime to the effluent stream. Auxiliary equipment includes a port for loading bags of lime to the hoppers of the feed mechanism with dust control protection and a charcoal scrubber to purify the gases vented from the plant sewerage system. The bags of lime are opened in a hood-shaped enclosure connected to an exhaust fan.



This dust-laden air is drawn through a Schneible-type water-washed column before being discharged to the atmosphere.

A separate system consisting of an exhaust fan and a chamber holding frames of activated carbon draw air from the vent chambers of the water-carrying mains and adsorb any malodorous fumes which are occasionally liberated.

Plans are nearing completion to separate the storm sewer water through a separate system which by-passes the liming station and public sanitary system discharging the stream to a local brook. A settling pool equipped with a scum-collecting baffle will monitor the water from the storm system and, if acid should accidentally run into this system, a pH controlled gate will divert the flow through the liming station.

### Summary

The experience of Hoffmann-La Roche in Nutley has shown that activated carbon is the most effective method of arresting air-borne odors which cannot be easily destroyed by chemical scrubbing solutions. This method is convenient to operate and has a high capacity resulting in a fairly long adsorbing cycle. The flexible design of the incinerator has made it possible to dispose of large quantities of a wide variety of liquid and solute wastes in a completely innoxious manner, even to the extent of disposing of objectionable aqueous solutions. The sewerage liming station provides adequate and automatic control of the condition of all plant effluents entering the public sewers and waterways.

### Discussion

**John Hardy** (Du Pont Co., Wilmington, Del.): Why did you go to so complicated a design on the carbon absorber? Was it pressure drop?

**Fred Lorentz:** That principally. As you realize, in an air-conditioning unit pressure drop is very important. Fan characteristics are such that if the resistance of the bed were doubled, the flow of air would be cut to less than half of what we hoped for in 12,000 cu.ft./min. It is necessary to keep the pressure drop as small as possible, to keep the air-handling capacity high with a reasonably low power consumption. As it is now, the bed is about 1 in. thick and the total cross-sectional area is about 1000 sq.ft. of carbon surface.

**John Hardy:** What was the pressure drop through this system?

**Fred Lorentz:** Three quarters of an inch of water, static pressure.



Fig. 3. Waste Liquor Spray Removed from Its Socket in Side Wall of Incinerator Chamber

**Anonymous:** Would you describe a couple of things you tried which did not work. Perhaps you tried some aqueous solutions for absorption?

**Fred Lorentz:** We did. It was believed that alkaline solutions would absorb the acid sulfide smell, but such a scrubber did not work. Then an alkaline sodium hypochloride solution was used in the hope that the bleach would oxidize the odors. This system was not successful in containing the garlic-like dithio formate odors. Acid oxidants are of no value since they would immediately break down the sodium dithio formate and give acid sulfide fumes. This is an impure mixture, sodium dithio formate being the least malodorous compound in this mixture. Serious consideration was

given to the use of ozone as an oxidizing system for destroying the odors but the engineering aspects of it were too expensive and too uncertain for it to be seriously exploited.

We would be interested to hear from anyone who has faced a problem of this type and has been able to destroy the odor chemically because it is a problem of the destruction of the odor, not its simple adsorption.

**Hartley Laboratories Representative:** Have you tried this method on fermentation wastes of any sort?

**Fred Lorentz:** Fortunately the odor from the few fermentation processes we have is no serious problem, so we haven't tried it.

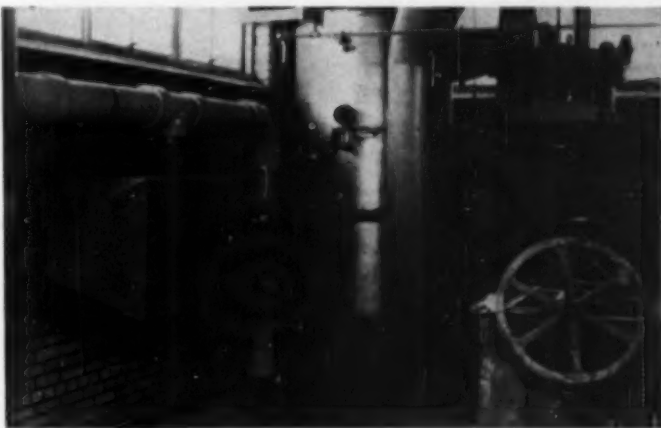


Fig. 4. View of Lime Dust Scrubber and Sewer Vent Charcoal Absorber in Liming Station

# BEET SUGAR PROCESS WATERS— TREATMENT AND UTILIZATION

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THE slow but consistent degradation of the lakes, rivers, and waterways of the United States by pollution from domestic sewage and industrial wastes has finally aroused nation-wide recognition of the problem. This recognition culminated on a national scale by the passage of Public Law 845 by the Eightieth Congress in 1948. The law provides for a nation-wide water pollution control program under the jurisdiction of the Public Health Service of the Federal Security Agency. Such legislation has brought the focus of attention on large waste-producing industries and the beet sugar industry finds itself on the list of offenders. However, the problem of recovery or elimination of wastes from beet sugar factories is an old one.

The beet sugar industry was established on a profitable basis in the United States at Alvarado, Calif., in 1879. Since that time, development of the beet sugar industry has been rapid. Today sugar beets are grown by about 80,000 farmers

in 21 different states. During 1947 there were 85 beet sugar factories (2) operating in 16 states, having a daily slicing capacity of 153,400 tons of beets.

The beet sugar industry generally provides about one fourth of the total sugar consumed in the United States. In 1947 this amounted to 1,575,060 tons of refined beet sugar (18). This quantity of refined sugar necessitated the growing, harvesting, and processing of 12,504,000 tons of sugar beets. Thus, it can be readily seen that the beet sugar industry is a sizable one, and is an important part of our present economy.

## Beet Sugar Wastes

The beet sugar industry produces five wastes that are of interest to sanitary engineers. They are:

1. Flume water used for transporting and washing the beets.
2. Process waste water consisting of the "battery wash," which results from

the operation of flushing the exhausted cassettes from the diffusion battery cells, and the "pulp press water" resulting from the partial dewatering of the exhausted pulp.

3. Lime cake or lime slurry resulting from the carbonation process.
4. Evaporator condensing water from multiple-effect evaporators and vacuum pans used to concentrate sugar solutions.
5. Steffen's waste resulting from the additional extraction of sugar from the molasses employing the Steffen's process.

While this paper is concerned solely with the treatment and utilization of the process waste water, a short discussion of each waste is necessary to explain the relative significance of this development. The source of these wastes and a schematic flow sheet of the manufacture of beet sugar are shown in Figure 1.

**Flume Water.** The flume water, consisting of the transport water and the water used in the beet washer, is a large volume waste. It has a high suspended solids content of essentially dirt, sand and debris, but its characteristics depend considerably on the nature of the weather during harvest and the extent of beet spoilage in the stockpile. The volume of the waste may vary from 2,000 to 3,000 gal./ton of beets sliced. The Biochemical Oxygen Demand (B.O.D.) of the flume water varies considerably and reflects the condition of the beets being processed. Fluming of partially decomposed and imperfect beets generally results in a significant increase in the B.O.D. of the waste. The 5-day 20° C. B.O.D. of waste normally varies from 75 to 300 p.p.m. and the suspended solids (S.S.) from 150 to 600 p.p.m. The problem imposed by the flume water is not a difficult one, in that it lends itself readily to conventional methods of sewage treatment. Recirculation and reuse of this waste employing sedimentation, and in some cases chemical treatment, have essentially solved this waste problem.

**Lime Cake.** The lime-cake problem is of minor importance since the waste is generally disposed of by lagooning or a utilization method. In many instances, the lime-cake slurry after drying in ponds, is sold to local farmers for its agricultural and fertilizing value. It also appears feasible to eliminate the dilution of the lime cake to a slurry and to dispose of the cake in its semidry state. The volume of drainage from lime storage ponds was reported by Eldridge (7) to be approximately 75 gal./ton of beets sliced, having a 5-day B.O.D. of approximately 1400 p.p.m. Occasionally the lime cake has been used in allied treatment processes for its value as a coagulant.

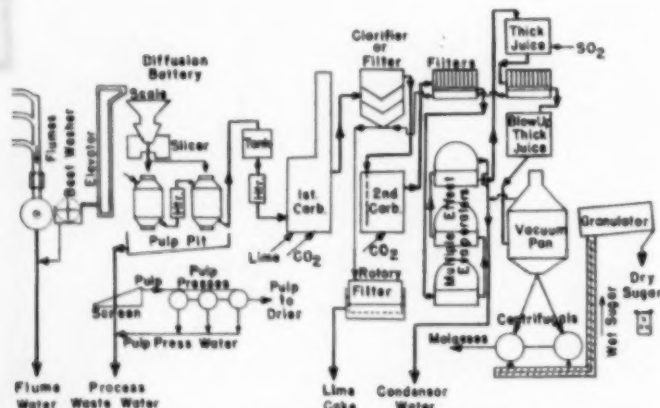


Fig. 1. Flow Sheet of Beet Sugar Manufacture

**Condenser Water.** The evaporator condensing water is a rather innocuous waste in that it is not very strong on a B.O.D. or S.S. basis. Its oxygen-demanding capacity is generally determined by the amount of carry-over and vapor entrainment, which depends on operating conditions and the efficiency of the equipment employed. One significant objection to the discharge of this waste is its relatively high temperature. Some factories have overcome this by installing cooling ponds and reusing the water either for condensing purposes or for fluming the beets.

The B.O.D. and S.S. content of this waste may vary from 10 to 80 p.p.m. The volume of the waste is reported by McDill (12) to be approximately 1400 gal./ton of beets sliced. The population equivalent is from one to six persons per ton of beets processed.

**Steffens Waste.** The waste resulting from the additional extraction of sugar from the straight house molasses, by the Steffens' process, is known as the Steffens waste. It is relatively small in volume, but extremely high in oxygen-demanding properties. Eldridge (7) reports the waste to be about 120 gal./ton of beets sliced, having a 5-day B.O.D. of about 10,000 p.p.m. The waste contains from 5,000 to 7,000 p.p.m. of sucrose, plus a considerable amount of organic nonsugars that have been concentrated in the waste by repeated extraction of sugar. The waste is extremely high in dissolved solids and has been the object of many utilization studies. In recent years factories which have employed the Steffens process have evaporated the waste in multiple-effect evaporators, and have sold the concentrated product to processing firms which have processed the waste further to recover valuable amino acids. The most notable of these is the recovery of glutamic acid in the commercial form of monosodium glutamate. In addition, the market value of the straight house molasses has been sufficiently high in many instances that it was not economically feasible to operate the Steffens house.

**Process Waste Water.** The process waste water, which consists of the "battery wash water" and the "pulp press water," is the most objectionable waste from a beet sugar factory not employing the Steffens process. Figure 2 is a flow diagram showing the operation of a diffusion battery and the origin of the process waste water.

The process waste water has a sugar content varying from 800 to 2500 p.p.m. as sucrose, plus a considerable amount of organic nonsugars in solution. The 5-day B.O.D. of the waste may vary from 1,000 to 2,500 p.p.m. depending on

TABLE 1—Typical Analyses of Beet Sugar Process Wastes

Determination		Pulp Press Water	Process Waste Water
Suspended Solids	ppm	1,500	1,800
Volatile Solids	%	80	75
Fixed Solids	%	10	25
Total Solids	ppm	4,000	3,800
Volatile Solids	%	75	70
Fixed Solids	%	25	30
5-Day 20°C. B.O.D.	ppm	2,800	1,900
Chem. O <sub>2</sub> Demand (Microplate Method)	ppm	2,000	1,400
Protein N as N	ppm	90	82
NH <sub>3</sub> N as N	ppm	5	15
Sucrose	ppm	1,000	1,500

operating conditions. A considerable portion of the B.O.D. of the waste results from its sugar content, essentially sucrose, with only a small amount of invert sugar normally present. The sugar content of the waste and consequently, the B.O.D., depends to a great extent on a large number of factors, such as the size and condition of the cosettes, operation of the battery, leaks from the cells, and operation of the plant in regard to the amount of water used for the diffusion process. The population equivalent of the waste ranges from 15 to 60 persons per ton of beets processed.

The waste has a S.S. content of about 1,000 p.p.m. or more, consisting mainly of small particles of pulp and dirt. The amount of pulp present is dependent upon the fineness of the fanger screen, as well as the set of the pulp presses.

The organic nonsugar content of the waste is relatively high, the protein content alone amounting to 300 to 500 p.p.m. The temperature of the waste at discharge is approximately 50° C. Typical analyses of process waste water are shown in Table 1.

The volume of process waste water may vary from 300 to 500 gal./ton of beets processed. Eldridge (7) reported the volume of waste as 660 gal./ton; however, that figure is liberal, especially for plants employing water conservation practices. At the present time, many factories use the process waste water for washing the battery cells prior to recharging with fresh cosettes, and in this way have considerably reduced the volume of waste. The writer's experiences in two beet sugar factories in Ohio tend to indicate a figure of approximately 325 gal./ton. It must be noted, however, that both these plants have given considerable attention to pollution abatement; hence, they probably represent the lower range of waste volumes.

## General Problem

Numerous attempts have been made to treat and reuse the process waste water by the beet sugar industry. The investigations concerned with this waste have been, for the most part, undertaken in England and in Europe. Such studies, of course, were brought about by a more critical need in those areas due to the concentration of population and industry than has been experienced by the beet sugar industry in the United States.

Considerable investigational work was done on biological treatment methods as a means of final treatment and disposal of the waste, but little success was attained, due largely to the characteristics of the waste and its seasonal duration. In recent years, attention has been directed more towards the reuse and utilization of the process waste water with the purpose of recovering the sugar and the water. Wintzell (17) described the development of a patented Wintzell-Lauritzen process. The process consists of treating the pulp press water with sulfuric acid, or some other inorganic acid to a pH of 3.6 in order to precipitate the albumin in the waste. The precipitate is separated by decanting and centrifuging and the clarified waste water is returned to the diffusion process. The precipitated albumin is sold for use as a stock food supplement. There are several disadvantages to this process that are cited by MacDonald (11); such as, excessive corrosion caused by the low pH, loss of sugar in the waste due to inversion at the low pH, and a loss of pulp due to the dissolving action of the treatment on the pectins, etc., in the pulp.

Bachman (3) reported that the Wintzell-Lauritzen process is employed in 19 beet factories in Sweden and that little trouble has been experienced with corrosion. However, Bachman suggested that the tanks for the treatment units

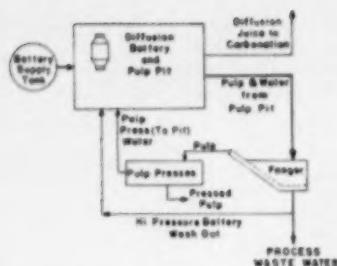


Fig. 2. Origin of Process Waste Water

should be constructed of either phosphor bronze or stainless steel.

MacDonald (10) discussed the recirculation of the process waste water for use as battery or extraction water without any treatment, to eliminate the organic nonsugars. He cited difficulties encountered due to gas produced during the diffusion process. In order to combat this difficulty, it was recommended that the recirculated wastes be heated to 90° C., and the pH be adjusted to about 7 with lime before returning the wastes to the diffusion battery. His most convincing argument was the saving in sugar for a factory successfully employing the reuse of the process waste water. He reported savings of 200 tons of sugar, 350 tons of molasses and 1125 tons of dry pulp for a factory having a 250,000-ton beet campaign.

It should be pointed out that there are two significant disadvantages to employing the process as proposed by MacDonald. First, the heating of the large volumes of returned water to about 90° C. involves considerable equipment and expense. Second, recirculation of the process waste water, without any treatment to remove organic nonsugars results in a build-up of dissolved and suspended solids in the recirculation system, and may decrease the circulation

of the diffusion juice in the battery, as well as place an additional load on the carbonation process.

McDill (12) discussed the experiences of the Buckeye Sugar Co., at Ottawa, Ohio, in regard to attempts at clarification of the process waste water with the return of a portion of it to the battery cells for juice extraction. Personal communication (6) with J. S. Eckert, superintendent of The Buckeye Sugar Co., revealed that during the campaign of 1941, when clarification and reuse were employed, considerable difficulty was experienced, due mainly to fermentation of the returned process waste water. Clarification with lime was also attempted, but was likewise discontinued because of adverse conditions in subsequent processes brought about by the lime treatment.

In practically all cases where reuse of the process waste water has been attempted and special attention not given to disinfection, operating difficulties due to fermentation were encountered. On this basis it seemed logical that a treatment and utilization process employing chlorine, a recognized disinfectant, would aid in solving the problem.

In view of the fact that the temperature existing in the return water circuit and in the cells of the diffusion battery varies from 50° to 70° C. or higher, it was readily apparent that the organisms responsible for the objectionable fermentations were thermophiles. The presumed disinfecting action of chlorine on those thermophiles was verified by the writer both in the laboratory as well as in actual plant studies.

A recent article by Allen et al (1) on studies made in England reported the effect of chlorine on strains of lactobacilli isolated from the diffusion battery. Their results showed that chlorine dosages of 40 p.p.m. applied to the return water acting for 25 to 30 min. at 55° C., in laboratory samples, destroyed more than 99% of the bacteria present and virtually eliminated the lactobacilli. Plant experiments with small chlorine dosages (19 p.p.m.) applied to the battery supply tank resulted in an increase in pH and a decrease in corrosion in the return water circuit. Findings of Allen et al. are in good agreement with many observations of this investigation.

Dormal (5), a European investigator, has reported on an attempt to reduce fermentation in the diffusion battery by the use of hypochlorous acid. A rather elaborate setup was required to facilitate passing a chlorine solution through contact beds of calcium carbonate to neutralize the hydrochloric acid before adding the solution to the battery. However, the operation of this process, which requires maintaining the diffusion wash water separate from the pulp press

water, created about a 10% decrease in the daily capacity of the plant, which is a significant economic disadvantage.

While in these processes an attempt has been made to utilize the disinfecting action of chlorine under various conditions, it is apparent that a consideration of them has been limited to only one aspect of the problem. Attention has been focused on corrective measures to aid in solving operational problems attributed to fermentation during the diffusion process, rather than in the direction of the purification of the water, in order to permit its most beneficial effect on the operation of the factory. The purpose of this paper is to summarize the research and development of such a purification and utilization process in the laboratory as well as the results of the actual operation of the process on plant scale in two different factories.

It should be noted that the treatment and utilization process, as described, is directly applicable only to those plants employing the conventional cell-type diffusion battery. The process does not apply to the newer factories employing the patented continuous diffusion batteries.

The economic justification of the dual approach of the recovery of appreciable quantities of sugar, and at the same time the complete elimination of the waste from stream pollution considerations are apparent.

### Experimental Procedure

Chlorine has been successfully applied in the treatment of a wide variety of industrial wastes. This is attributed to its ability to act in a number of ways to bring about a desired end. The three most notable characteristics of chlorine are as follows:

1. A potent oxidizing agent. Advantage is taken of this property in the treatment of cyanide wastes which are oxidized to unobjectionable end products (4).

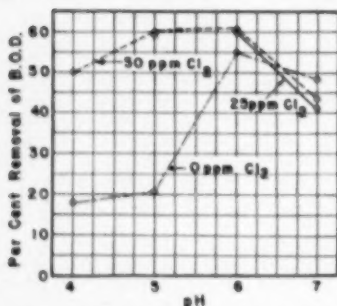


Fig. 3. Removal of B.O.D. from Process Waste Water with Chlorine

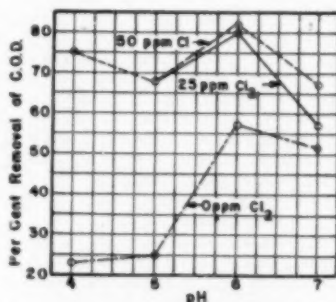


Fig. 4. Removal of C.O.D. from Process Waste Water with Chlorine



2. An effective coagulant under proper conditions, especially for protein matter. This property has been exploited by Dr. Halvorsen in his method of packing house waste treatment (8).
3. An effective disinfecting agent. This role of controlling biological growth has been effectively used in the paper industry to allow recycling of water to reduce fiber losses and conserve water (16).

The laboratory investigations on process waste water were conducted using this multiple-action chlorine, with the development of a cheap and effective method of treatment as the objective. In view of the characteristics of process waste water, previously discussed, it is apparent that chlorine is well suited for its role in the treatment process.

#### Laboratory Method

Chemical coagulation of process waste water was studied under laboratory conditions using several dosages of chlorine at each of a number of pH levels. The studies were conducted at room temperature, about 25°C., due to lack of available facilities for conducting the studies at 50°C., which is the temperature encountered in practice. Operation of the jar studies was uniform and consisted of a rapid mix for chemical dispersion of one minute, followed by a 30-min. flocculation period, and a 60-min. sedimentation period of quiescent settling. At the end of 60-min. sedimentation, samples of the supernatant were drawn off and analyses were made on the raw and treated wastes, in order to determine the efficiency of the treatment at each pH level. B.O.D. and Chemical Oxygen Demand (C.O.D.) tests were made on the raw and treated wastes. For the C.O.D. determination, a modification of Rhame's (14) method of determining the C.O.D., using potassium dichromate as an oxidizing agent in an acid solution was used. The procedure consisted of a one-hour period of digestion in an all glass reflux apparatus similar to that proposed by Ingols and Murray (9).

#### Experimental Results

The treatment of process waste water with chlorine yielded rather remarkable results. Removals of B.O.D. as high as 60% and of C.O.D. of 80% were obtained with chlorine dosages as low as 25 p.p.m. at a pH of 6. Comparable results were obtained at a pH of 5, when chlorine was added; however, without chlorine the coagulation at pH 5 yielded poor results compared with the chlorine-treated sample. Little difference in removals was obtained by chlorine dosages of 25 or 50 p.p.m. or higher. It should be noted that at the optimum pH for coagulation of about 6, almost as good B.O.D. removals were obtained at that pH without the addition of chlorine. However, the C.O.D. removals were about 25% lower than those attained with 25 p.p.m. of chlorine. Figures 3 and 4 demonstrate the effect of chlorine dosage and pH on the per cent removal of B.O.D. and C.O.D.

While the per cent removals of B.O.D.

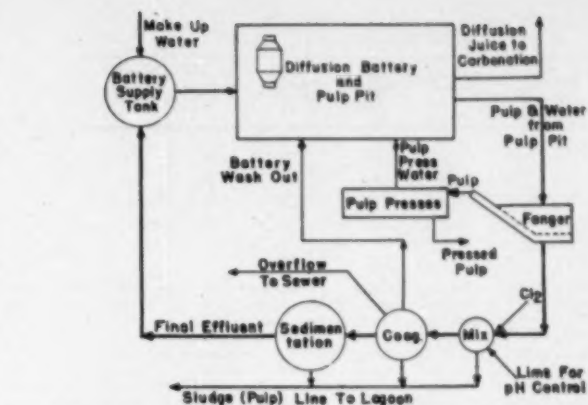


Fig. 5. Flow Diagram of Treatment and Utilization Process at Buckeye Sugar Co.

and C.O.D. appear rather high in view of the sugar content of the waste, several factors should be explained. First, the samples of waste were obtained at a time when the sugar content of the waste was low, and the organic nonsugars considerably higher than normal, due to the fact that the factory had slowed down waiting for beets, which resulted in a lengthening of the actual period of diffusion. Second, the waste was transported from Ohio and was kept for several weeks for laboratory experimentation, although a preservative was used. These two factors may have had influence on the numerical results; however, the significant observations are the difference in removal between the control and the chlorinated samples and the effect of pH on the organic removal.

It is important to note that although the B.O.D. removal from the waste was approximately 60% at the optimum pH conditions, the actual removal and stabilization of organic nonsugars is considerably greater. This is explained by the fact that the B.O.D. test, as well as the C.O.D. determination, measures the oxygen required for partial or complete stabilization of the organic content of the waste, including both sugars and nonsugars. Since the chlorine treatment of the waste is specific for the nonsugars, having no effect on the sucrose content of the waste, the removal of B.O.D. and C.O.D. achieved by the treatment was accomplished by the reaction of chlorine with the organic nonsugars of the waste. Hence, the actual removal of organic nonsugars was considerably greater than that expressed in terms of the original B.O.D. and C.O.D. of the waste. This confirmed the theoretical consideration that the chlorine treatment might serve as a defecation process for the removal of organic nonsugars from the process waste water.

The treatment of the process waste water was not attempted at levels lower than pH 4, in order to avoid chemical inversion of sucrose to the invert sugars glucose and fructose and the resultant loss of marketable sugar.

#### Ottawa Plant Studies

**Description of Buckeye Sugar Factory.** As a result of the findings of the laboratory investigation, arrangements were made with the Buckeye Sugar Co., Ottawa, Ohio, to install and operate the treatment and utilization process on an experimental basis during the 1948 campaign.

The factory of the Buckeye Sugar Co. has a rated capacity of 1,000 tons/24 hr., and operates what is known as a straight house. The plant employs a standard diffusion battery consisting of 14 bottom dump cells, each cell having a capacity of 3 tons of beets. Operation at rated capacity necessitates the loading and emptying of a cell every 4.3 min.; hence, the flow of process waste water is almost continuous. The carbonation process for the removal of nonsugars from the diffusion juice is operated on a batch basis. Consequently, it lacks some automatic control features associated with the more modern continuous carbonation process. The exhausted pulp is pressed in rotary presses, dried to about a 14% moisture content in a double pass rotary drier, and is sacked and sold as stock feed. The pulp press water is returned to the pulp pit to facilitate removal of the pulp.

Handling of the process waste water at the plant for the last few years, and prior to the installation of the treatment and utilization process, consisted of screening and partial sedimentation of the waste prior to its discharge, with none being reused for battery supply water.

The mixture of pulp and water was pumped to a pulp fanger, essentially an inclined screen having openings between the bars of approximately 1/8 mm., along which the exhausted pulp was dragged by means of wooden flights, thus separating the larger pulp particles from the process waste water. The process waste water was then

TABLE 2 Effect of pH on Removal of S.D., S.B., and Org. N in Coagulation Study Under Plant Conditions With a Chlorine Dose of 75-100 ppm

pH Range S.D. of Treatment	Per Cent Removal of S.D.	S.D. of Untreated P.W.	Per Cent Removal of S.B.	Org. N of Untreated P.W.	Per Cent Removal of Org. N
5.7 - 6.2	1,700	40	1,560	30	61
6.3 - 6.6	1,500	42	1,460	34	62
6.6 - 7.2	1,800	36	1,110	35	66
8.6 - 9.4	1,700	37	1,220	32	69

passed through a 40-mesh rotary screen and a 1,500-gal. tank prior to its discharge to the sewer. The 1,500-gal. tank served as a combined settling tank and pump sump for the high pressure battery washout pump, thus permitting the reuse of the process waste water to wash out the cells.

The treatment installation used in these plant experiments consisted of two tanks, 6 ft. in diameter by 7 and 10.5 ft. in depth, and a tray-type sludge thickener which was used as a final sedimentation tank. The sludge thickener was 8 ft. in diameter and 11 ft. deep and was equipped with conical bottoms to permit sludge removal.

Figure 5 shows a flow diagram of the treatment and utilization process as employed at the Buckeye Sugar Co. The chemicals were added to the waste in Tank No. 1; the chlorine solution was introduced by means of a silver tube diffuser into the flow of the waste at the inlet, and the lime slurry was added through a rubber hose into the center of the tank, in order to maintain proper pH conditions. For chlorination, a Wallace and Tiernan portable main sterilizer with a maximum capacity of 300 lb. of chlorine/day was used. The lime slurry for pH control was fed by means of an Inflico lime feeder.

**Preliminary Treatment Studies.** The first week of operation of the treatment process was spent in an attempt to determine the optimum condition of operation in the plant. During this period, a study was made on the effect of pH on the efficacy of the treatment. A chlorine dosage of from 35 to 45 p.p.m. was employed, and lime or sulfuric acid was fed to maintain the pH of the treatment at the pH level under investigation. The flow through the treatment unit during this initial study was approximately one half of the total process

waste water flow, or about 165,000 gal./day. The effluent from the treatment unit was discharged directly to the sewer. The theoretical detention time provided by Tank No. 3 when treating approximately 50% of the total process waste water flow was 40 min., and about 25 min. when 75% of the total flow was treated. Twenty-four hour, hourly composited samples were collected of the influent and effluent for each treatment pH level investigated, and were analyzed in the laboratory.

Table 2 reports the condition of operation and the removals of suspended solids, B.O.D. and organic nitrogen achieved by the treatment of the process waste water at each pH level investigated.

Probably the most significant conclusion of the preliminary coagulation study under actual conditions was that removals of from 45 to 51% of the organic nitrogen or protein material was accomplished at the pH range from 5.7 to 6.6. It should also be noted, that the per cent removal of protein material in the pH range investigated decreased as the pH increased, independent of the removal of suspended solids.

From results of the coagulation study under plant conditions, the optimum pH range for treatment with chlorine appeared to be from 5.7 to 6.6, which confirmed the laboratory findings.

**Operation of Treatment and Utilization Process.** Following the preliminary studies made to determine the optimum pH for

coagulation, the flow of treated process waste water, representing 50% of the total flow, was diverted to the battery supply tank. This condition was maintained for four days to observe the effects of the process on the operation of the factory. Results were so favorable that the amount of treated process waste water returned to the diffusion battery was increased to a minimum of 75% of the total flow, and continued at that level throughout the remainder of the campaign. The hydraulic characteristics of the treatment unit limited the maximum quantity of process waste water to be treated and returned to the battery supply tank, from 75 to 85% of the total flow.

A chlorine dosage of from 35 to 45 p.p.m. was applied to the waste throughout the experiment. With this dosage, it was possible to maintain residuals of 1 to 2 p.p.m. free chlorine at the end of a 10-min. contact period.

Considerable quantities of pulp and sludge were removed by sedimentation and were disposed of by lagooning along with the lime cake. It should be noted that the characteristics of the sludge and pulp particles indicated a possible economic return, if fine screening of the sludge was employed. The screenings could be added to the rotary presses and driers for subsequent recovery as dried pulp. In the event the particles were so fine that they would be consumed in the drier, without significantly increasing the yield of pulp, the method of handling would at least eliminate the disposal of the sludge.

**Results of Operation.** Operation and efficacy of the treatment as a defecation process are presented in tabular form in Table 3. The magnitude and removal of B.O.D., suspended solids, and organic nitrogen by the treatment unit in the return water circuit are reported for each day of operation and condition of treatment.

The effect of the treatment and utilization process on the elimination of B.O.D. from the plant waste and the recovery of sugar are shown in Table 4. The elimination of 2 to 4 lb. of B.O.D. from the sewer, per ton of beets sliced, is important from the standpoint of stream pollution abatement. Likewise, the recovery of 2 or more lb. of sugar/ton of beets sliced, represents a significant economic gain.

Table 5 presents a summary of a few of the important control analyses in the operation of the factory before and after the treatment and reuse of the process waste water.

An important observation to be made from the data indicates that the sugar content of the pulp and pulp water did not show an appreciable increase following the reuse of the treated waste for extraction water. A statistical analysis was made of the daily averages of the data for the 10 days preceding the operation of the process, and a similar period during its operation, to determine if there was a significant difference brought about by the treatment. At the probability level of 95% (1 chance in 20 of being wrong) an analysis by means

TABLE 3 Results of Operation of the Treatment and Utilization Process With a Chlorine Dose of 35-45 ppm, and Its Effect on the Removal of B.O.D., S.B., and Org. N.

Day of Operation	Per Cent P.W. Returned to Battery	pH Range of Treatment	5 Day B.O.D.		Suspended Solids		Organic Nitrogen	
			Untreated P.W.	Removed	Untreated P.W.	Removed	Untreated P.W.	Removed
			ppm	ppm	ppm	ppm	ppm	ppm
34	50	6.6-6.9	1,300	1,380	33	2,050	74	74
35	50	5.9-6.4	1,300	1,450	17	2,200	76	83
36	50	6.7-7.1	1,300	1,510	40	2,200	40	87
37	50	6.6-6.9	1,800	2,000	15	2,250	60	87
38	75	6.5-7.4	2,100	1,930	43	1,600	69	80
39	75	7.2-7.6	2,300	2,380	27	1,600	50	82
40	75	6.0-6.7	1,300	1,660	—	1,700	47	90
41	75	5.6-6.2	1,300	1,210	—	2,500	43	82
42	75	5.8-6.1	2,100	1,830	42	1,600	25	73

Note: All analyses are reported on 24 hour, hourly composited samples.



of the "t" test (15) indicated that there was no significant difference in the results obtained during these two periods in regard to the sugar content of the pulp and pulp water.

Similar statistical analyses were applied to the data on the purity of the diffusion juice, first carbonation juice, and thin juice. Although the mean of the purity data on the diffusion juice, during the ten days' operation of the process, was 0.6% higher than that of the previous ten days, the difference caused by the treatment process was not significant at the probability level of 95%. However, there was a significant difference in the results of the purity of the diffusion juice achieved by the treatment, at the probability level of 90% (one chance in 10 of being wrong). While these results are not conclusive, they indicate that the treatment process increased the elimination of nonsugars in the diffusion battery.

The mean of the data for the purity of first carbonation juice and thin juice was also higher for the 10 days' operation of the treatment than that of the previous 10 days. However, there was no significant difference in the data at the probability level of 95%.

### Fremont Plant Studies

**Description of Fremont Factory.** As a result of the successful experiment at the Buckeye Sugar Co., arrangements were made at the request of the Great Lakes Sugar Co. to continue the plant scale experiments at its Fremont (Ohio) plant. This was possible as the Fremont plant had approximately one month's processing remaining after the campaign ended at the factory of the Buckeye Sugar Co.

The Fremont plant is a comparatively modern beet sugar factory, and has a rated capacity of 1100 tons of beets/24 hr. Facilities of the plant are such that during the 1948 campaign 92,000 tons of beets were processed with a daily average of more than 1200 tons. The factory employs a conventional 12-cell diffusion battery; each cell has a capacity of approximately 3.7 tons of beets. The cells are equipped with quick-opening, bottom dumps, and require a minimum amount of washing.

The carbonation process is continuous, and employs automatic pH control. In short, the defecation of nonsugars consists of treatment with lime and carbon dioxide under carefully controlled conditions followed by sedimentation. The sedimentation consists of a separation of the lime sludge from the clear juice in a multiple-tray-type, Dorr clarifier. The sludge is filtered on vacuum filters, washed to reduce its sugar content, and diluted with process waste water to a slurry, in order to facilitate pumping to the waste lagoon.

Facilities for handling the process waste water included a conventional fanger for the separation of the pulp from the water, and a tank which was used as a pump sump for the high pressure battery washout pump and gravity return line to the battery pit.

TABLE 4 The Elimination of H.C.D. from the Sewer, and the Recovery of Sugar by Operation of the Treatment and Utilization Process

Day of Operation	Pounds of 5 Day H.C.D. Eliminated From Sewer Per Day	Pounds of Sugar Recovered Per Day
24	1,720	1,680
25	1,640	1,680
26	1,890	1,680
27	2,800	2,450
28	3,420	3,920
29	4,460	4,310
40	3,970	3,480
41	2,240	2,480
42	2,420	2,980

Note: Based on Avg. Plant Production of 900 tons per day

The process waste water overflowed from the tank into the flume water circuit, and thence to the lagoon.

**Operation of Treatment and Utilization Process.** Installation of the treatment facilities at the Fremont plant consisted of a pump and connecting piping from the existing holding tank to the battery supply tank. A Wallace and Tiernan portable main sterilizer was connected to feed the chlorine solution in the suction side of the pump. Figure 6 shows a flow diagram of the treatment and utilization process as employed at the Fremont plant.

Facilities were not available for pH control of the chlorinated waste. Likewise, sedimentation of the waste before return to the battery supply tank was eliminated; however, removal of the nonsugars took place in the Dorr clarifier in the carbona-

tion process. This practice eliminated the possibility of economic recovery of pulp, and also placed an additional load on the diffusion battery as well as the carbonation process.

Chlorine dosages from 40 to 60 p.p.m. were applied to the process waste water throughout this experiment. The acidity of the applied chlorine solution lowered the pH of the returned water from 6.8 to as low as 4.75. However, this pH existed in the waste for a short time, as the mixing of the waste with the make-up water in the battery supply tank resulted in a significant increase in pH. The pH of the composite battery supply water remained in the range of 6.8 to 7.5. A free chlorine residual varying from 0.5 to 2.0 p.p.m. was present in the battery supply water as it entered the diffusion cells.

Approximately 65% of the total process

TABLE 5 Summary of the Buckeye Sugar Operating Data Before and After Operation of Process

Day of Operation	Sucrose Content of P.W.W. %	Pulp Water % Sucrose	Pulp % Sucrose	Diffusion Juice Purity	1st Carb. Purity	Thin Juice Purity
Ten Days Prior to Operation of Process						
24	.14	.22	87.3	89.6	89.5	
25	.11	.17	87.0	87.3	91.4	
26	.12	.18	87.6	89.9	89.3	
27	.14	.19	88.3	91.1	91.3	
28	.12	.19	85.8	89.6	90.1	
29	.15	.21	86.1	90.1	90.0	
30	.18	.24	86.3	89.3	89.9	
31	.18	.24	86.9	89.6	89.2	
32	.19	.24	87.4	89.8	91.6	
33	.20	.26	87.5	88.7	89.0	
Mean	.152	.214	87.0	89.3	90.1	
Ten Days During Operation of Process						
34	.16	.23	87.6	88.9	89.3	
35	.17	.26	87.0	90.9	90.2	
36	.19	.27	88.6	90.2	89.6	
37	.15	.19	87.1	91.0	90.9	
38	.14	.18	88.0	89.4	90.1	
39	.16	.20	88.0	90.7	90.9	
40	.17	.16	88.0	90.2	91.3	
41	.16	.19	87.5	90.0	89.9	
42	.20	.15	88.0	89.3	90.0	
43	.24	.15	87.7	89.5	90.0	
Mean	.176	.202	87.6	90.1	90.2	

Note: All values are 24 hour averages.

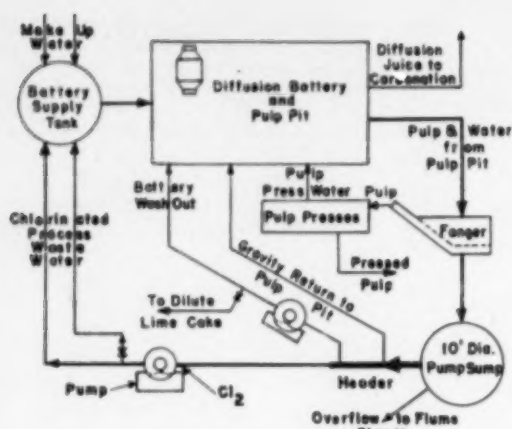


Fig. 6. Flow Diagram of Treatment and Utilization Process as Employed at Fremont Plant of Great Lakes Sugar Co.

waste water was returned to the diffusion process during the first week of operation. For the remainder of the campaign (two weeks), approximately 80 to 85% of the total process waste water was returned to the battery. However, this amounted to from 98 to 100% of the flow normally wasted to the sewer. The remaining 15 to 20% of the total flow was used to dilute the lime cake to a slurry to facilitate disposal by pumping to the lagoon.

**Results of Operation.** Results of the operation of the modified treatment and utilization process were satisfactory, in view of the type of installation. However, some operational difficulties were encountered that were attributed to the

lack of coagulation and sedimentation. In this type of an installation, the actual sedimentation or removal of nonsugars which are normally removed by sedimentation, are removed in the carbonation process, and settle out in the Dorr thickener. The possibility of clogging the diffusion cells, and thus reducing circulation and encouraging channeling, is ever present when sedimentation of the treated process waste water is not practiced. Also, this type of operation transfers the organic nonsugars from the process waste water to the lime slurry and does not give maximum alleviation of the disposal problem.

TABLE 6. Per Cent Elimination of Non-Sugars by Beet End For 21 Days Before and After Operation of the Process

Before Treatment		After Treatment	
Day of Operation	Per Cent Elimination of Non-Sugars by Beet End (Battery & Carbonation)	Day of Operation	Per Cent Elimination of Non-Sugars by Beet End (Battery & Carbonation)
35	61.4	56	62.8
36	—	57	67.3
37	—	58	65.7
38	60.1	59	64.4
39	56.9	60	67.6
40	62.0	61	62.7
41	61.9	62	64.9
42	61.6	63	—
43	—	64	69.1
44	70.0	65	81.8
45	61.2	66	72.0
46	69.4	67	66.1
47	66.4	68	61.0
48	69.6	69	68.6
49	64.1	70	73.2
50	64.4	71	70.2
51	64.0	72	60.7
52	73.8	73	69.2
53	—	74	73.1
54	59.4	75	65.7
55	66.1	76	80.0
Mean	62.6	Mean	68.1

Notes: All data are daily averages as reported by the Great Lakes Sugar Company. Missing values not available.

Table 6 shows the effect of the treatment and utilization process on the per cent elimination of nonsugars by the beet end (battery plus carbonation) and the battery alone. The mean of the data on the per cent elimination of nonsugars for the 21 days during the operation of the process, is more than 5% greater than the mean of the data for the preceding 21 days. A statistical analysis of the data indicates that the treatment process produced a significant improvement in the per cent removal of nonsugars by the beet end, at a probability level of greater than 99% (less than 1 chance in 100 of being wrong). The increased elimination of nonsugars by the beet end during the operation of the treatment and utilization process was achieved while processing beets with an average apparent purity of only 0.3% less than the average for the preceding three weeks.

Tables 7 and 8 present a summary of the plant operating data for the 21 days immediately preceding and during the operation of the process. A significant increase occurred in the mean sugar content of the pulp and pulp water of 0.05 and 0.06% respectively, during the period chlorination was practiced. However, other factors may have been responsible for a portion of the increase in the sugar content of the pulp and pulp water. Some variables which may have affected the sugar content of the pulp and pulp water are:

1. Drying of the beets during storage, thus requiring a longer period of diffusion for normal extraction.
2. Poor cossettes resulting from working dried and partially frozen beets.
3. Operation of the factory's above-rated capacity under such conditions.
4. An increase in channeling effect due to the recirculation of process waste water having a considerable suspended solids content.

One of the most important facts shown by the data presented in Tables 7 and 8 is the increase in purity of the evaporator thin juice during the period of operation of the treatment and utilization process. The mean of the purity data of the thin juice during the treatment period is 0.5% greater than the mean of the data for the equivalent period before operation of the process. A statistical analysis of the data in Tables 8 and 9 indicates that the operation of the treatment and utilization process was responsible for a significant increase in the purity of the evaporator thin juice at a probability level of greater than 99%.

While an increase in the mean purity of from 91.4 to 91.9 does not seem of too great significance, inspection of an "Available Granulated Table" readily reverses this concept. According to data on per cent available granulated on dry

substance of sugar solutions, assuming a molasses purity of 60, an increase in purity as cited, increases the per cent available granulated sugar from 78.5 to 79.75 (13). An increase in available granulated of 1.25% on dry solids is of considerable economic importance.

### Comment

One of the interesting by-products of the field investigation was the apparent beneficial effects of the process on the recovery of the sugar in the factory. Runs were of sufficient length and the data of sufficient quantity to apply statistical methods of analysis which show that actually an increase in the purity of the diffusion juice and carbonated juices can be expected with proper operation of the treatment process. It should be noted that an increase in the purity of the thin juice during operation of the process may be as significant in terms of increased economic return on the recovery of sugar, as the tonnage of sugar retained in the plant each day by the treatment and reuse of the process waste water.

The actual sugar saving resulting from the operation of the treatment and utilization process is not clearly defined on the basis of factory operating reports. The procedure employed for calculating sugar losses in beet sugar factories is not applicable during the operation of the utilization process, and in some cases the method used leaves much to be desired.

Consider, for purposes of illustration, a typical value for the sugar content of the process waste water as 0.15% or 1500 p.p.m. sucrose, and the volume of waste equal to 100% of the weight of the beets processed (more correctly, approximately 135%), which is an industry-wide basis for comparison. This means, for every ton of beets processed, there is a loss equal to  $0.0015 \times 2000$ , or 3 lb. of sugar from this source alone. In itself that appears almost an insignificant quantity; however, when projected over a day's operation for one of the smallest plants in the industry (1000 tons of beets/day), the loss amounts to a ton and a half of sugar.

From a sanitary engineer's point of view, the elimination and reuse of a waste containing approximately  $1\frac{1}{2}$  tons of sugar a day for a 1000-ton plant must involve a recovery of that amount of sugar somewhere within the plant. It is apparent under such conditions that the sugar can leave the plant in one of three ways, which are: (1) As granulated sugar in the bag, (2) As sugar in the pulp, and (3) As sugar in the molasses.

As long as the purity of the syrup is maintained or increased, the normal extraction ratio of sugar in the bag to

TABLE 7 Summary of the Present Operating Data For the 21 Days Preceding the Operation of the Process

Day of Operation	Pulp Water % Sugar	Pulp % Sugar	Diffusion Juice Purity	Evaporator Thin Juice Purity
35	.11	.18	87.2	91.3
36	.11	.19	86.8	91.6
37	.12	.18	86.7	91.7
38	.15	.23	86.9	91.2
39	.21	.28	87.0	90.9
40	.15	.21	86.9	91.3
41	.13	.21	87.2	91.2
42	.17	.25	87.1	91.3
43	.15	.22	86.9	92.3
44	.14	.21	87.1	91.3
45	.13	.20	87.2	91.4
46	.12	.22	86.6	90.9
47	.12	.20	87.1	91.0
48	.15	.24	87.2	91.4
49	.14	.25	87.3	91.5
50	.11	.20	86.9	91.2
51	.13	.23	86.7	91.3
52	.13	.24	86.9	91.6
53	.13	.24	87.1	91.3
54	.16	.28	87.0	91.6
55	.15	.24	87.6	91.8
Mean	.141	.224	87.0	91.37

Note: All values are 24 hour averages as reported by the Great Lakes Sugar Company.

sugar in the molasses will be similarly maintained or increased. Thus, the sugar saved will appear as granulated sugar, sugar in the pulp and sugar in the molasses. In view of approximate current values of \$140 a ton for granulated sugar and \$65 and \$45 a ton for pulp and molasses respectively, the recovered sugar appearing in each product has significant economic value.

Plant scale operation of the process indicates that the cost of chemicals for operation should not exceed \$15 a day for a 1000-ton plant. Preliminary studies of the economics of the process re-

veal that the capital investment for the treatment installation could be amortized over a one-year period of operation with the savings above cost of operation. In addition, the treatment and utilization process completely eliminates the process waste water as a waste, and contributes materially to the improvement of the general processing conditions in the plant.

### Conclusions

The treatment of process waste water with chlorine dosages of from 25 to 60

TABLE 8 Summary of the Present Operating Data During the 21 Days Of Operation of the Process

Day of Operation	Battery Supply % Sugar	Pulp Water % Sugar	Pulp % Sugar	Diffusion Juice Purity	Evaporator Thin Juice Purity
56	.05	.14	.23	86.9	91.0
57	.05	.17	.26	87.1	91.4
58	.06	.17	.25	87.1	91.7
59	.07	.24	.32	87.7	92.2
60	.06	.20	.29	87.4	92.3
61	.05	.19	.27	87.1	91.6
62	.05	.16	.23	87.0	92.1
63	.05	.16	.23	87.2	91.7
64	.05	.13	.20	86.8	91.6
65	.06	.19	.26	86.7	92.2
66	.04	.19	.26	87.2	91.9
67	.06	.22	.27	86.9	92.2
68	.07	.22	.30	87.5	92.4
69	.08	.21	.31	86.9	92.2
70	.08	.21	.29	87.3	92.0
71	.09	.20	.27	87.4	92.0
72	.08	.22	.29	87.3	91.8
73	.15	.30	.35	86.8	91.9
74	.15	.26	.33	87.1	92.1
75	.17	.28	.33	86.6	91.3
76	.06	.15	.21	86.6	91.6
Mean	.074	.199	.274	87.0	91.87

Note: All values are 24 hour averages as reported by the Great Lakes Sugar Company.

p.p.m. in the pH range of 5.5 to 7.0, followed by sedimentation permits the most satisfactory reuse of the process waste water as battery supply water.

The following benefits can be attributed to the operation of the treatment and utilization process based on the observations of two full-scale applications of the process in the industry.

1. Complete elimination of the process waste water as a waste, thereby reducing the B.O.D. load from the straight house operation by 40 to 85 per cent.
2. Recovery of approximately two tons of sugar a day for a 1000-ton plant (4 lb./ton of beets).
3. Increase in the purity of the juices and syrups, thus, increasing the per cent available granulated and consequently, the net extraction of sugar for the plant.
4. Reduction in the loss of sugar due to bacterial inversion and fermentation in the diffusion battery.
5. Reduction of 33 per cent or greater in the water requirements for operation of the diffusion battery.
6. Conservation of the sensitive heat of process waste water.
7. Possibility of additional recovery of pulp by sedimentation and fine screening of the sludge.

#### Acknowledgments

The authors wish to express their appreciation to The Chlorine Institute, Inflico Inc., The Buckeye Sugar Co., and The Great Lakes Sugar Co., for their excellent cooperation and assistance in making the field investigations possible.

Special credit is due the Wallace and Tiernan Co., Inc., for financing the research, for the loan of equipment, and for their assistance in the conduct of the field studies.

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#### Discussion

**A. R. Nees** (Great Western Sugar Co., Denver, Col.): Did I understand that the pulp water is screened before it is chlorinated?

**E. A. Pearson**: Yes. Through the conventional fanger, a screen.

**A. R. Nees**: Not through a fine screen?

**E. A. Pearson**: No.

**A. R. Nees**: Then that is where you get the flocculation you talk about?

**E. A. Pearson**: Yes. The suspended matter is part of the flocculation. However, we have evidence that the action of chlorine also causes some flocculation.

**A. R. Nees**: I see. I have tried chlorination on screened wastes that went through a 30-40 mesh screen and I haven't been able to get a good flocculation.

**E. A. Pearson**: It is not the type of flocculation that you might normally encounter by conventional chemical precipitation. It does not remove the color with the suspended matter, such as you might do with lime coagulation. The treated water still has the opaqueness of the original waste.

**A. R. Nees**: May I ask how you separate this material before it goes back to the battery supply water?

**E. A. Pearson**: The proper way to separate it is through sedimentation units, so that the suspended and flocculated material will settle out.

## DISPOSAL OF SYNTHETIC ORGANIC WASTES

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THE story of the stream pollution abatement activities at the South Charleston (W. Va.) plant of Carbide and Carbon Chemicals Div. is one of action in which concrete reduction in stream pollution was made well before the detailed study of the technical aspects of the problem had been completed. This paper gives briefly the most important factors involved in the undertaking—the manner in which the subject was approached, some methods that were developed and used in the pollution-abatement program, and some different results accomplished to date. It should not be looked upon as a complete coverage of water pollution abatement or even as a complete coverage of this subject as applied to the Kanawha Valley, since there are additional programs under way to control other sources of stream pollution in that basin. It is specifically a

report of progress at one plant and may offer suggestions of similar action to other industrialists and cities facing questions of waste disposal.

**Critical Factors Involved in Stream Pollution.** The South Charleston plant of Carbide is located in the Kanawha River Valley and uses the waters of the Kanawha River for all usual industrial purposes. This valley, highly localized center of the chemical industry, extends for a distance of about 30 miles along the Kanawha River and centers on Charleston, W. Va.

The Kanawha River and its tributaries, on arrival at South Charleston, have drained an area of approximately 10,420 sq. miles of mountainous terrain which is occupied by 33.5% of the state's population or about 700,000 persons. This type of terrain causes both rapid

and large variations in flow volumes in the river due to quick run-off after heavy rains with a correspondingly rapid return to normal flow. The river is channeled for practically its entire length, and pool stages are maintained by a series of roller dams. This type of flow control maintains normal river levels, but, during periods of low river flow, it may allow wastes to accumulate in the pools above the dams. It is not conducive to rapid re-aeration nor to uniform waste loadings which are vital factors in stream recovery and on the ability of a stream to handle organic wastes.

The low normal flow of the river is approximately 1500 cu.ft./sec. (slightly more than one billion gallons per day) with a maximum temperature of 30° C. (86° F.). Under these conditions, which usually are approached during one or two periods each year, industry is pumping, for all industrial uses, approximately 1½ times the total flow of the river. A high percentage of the industrial usage is for cooling purposes only and the water returned to the river uncontaminated. However, if the temperature of the cooling water is raised high enough, the dissolved oxygen may be driven off and the water might possibly be completely deoxygenated by circulation through industrial cooling systems.

Carbide and Carbon Chemicals Div. produces approximately 300 different synthetic organic chemicals at South Charleston. A few groups of products which are manufactured are:

Alcohols	Ketones
Aldehydes	Acetates
Glycols	Amines
Ethers	Vinyl Resins

These are compounds of carbon, hydrogen, oxygen, and in the case of amines, nitrogen. Most of the vinyl resins contain chlorides. Substantially all these compounds, under either anaerobic or aerobic decomposition, will break down into simpler compounds.

There is little need to go into detail as to what constitutes river pollution. Suffice it to say that, in the case of the Kanawha River, the most serious result of domestic and industrial pollution is the low oxygen balance during periods of low flow. In other words—the water does not contain enough dissolved oxygen to decompose aerobically the organic material that has been added to the river. The difference between the oxygen requirement and the available oxygen is called the oxygen balance. When all of the oxygen has been depleted, anaerobic decomposition begins, and this may lead to a septic condition in the river with the formation of products such as ammonia, methane, and

hydrogen sulfide. Taste and odor control is the number two problem in the case of the Kanawha River.

Figure 1 shows the per cent saturation of dissolved oxygen vs. temperature of Kanawha River water pumped into the South Charleston plant. It shows that under high summer temperatures the amount of dissolved oxygen in the inlet water has been greatly reduced by pollution sources in the upper drainage basin. It shows that, at a river temperature of 17° C. (62.6° F.), the water is approximately 50% saturated; at 21° C. (69.8° F.) saturation is about 30%, and at 28° C. (82.4° F.) about 5 per cent.

Figure 2 shows the oxygen balance in the Kanawha River during a low flow period in the summer of 1948 at which time the pH of the river varied from 7.0 to 7.5. The South Charleston plant is situated between Patrick Street and Dunbar, and a marked increase is shown in the deficit of dissolved oxygen between these two points. Actually, the decrease of approximately 120,000 lb. per day is caused not only by the industrial pollution from several plants in the area, but also by the domestic pollution from the town of South Charleston.

Figure 3 shows the accumulated biochemical oxygen demands from both domestic and industrial sources and a cumulative dissolved oxygen curve. The latter includes all oxygen present in the stream prior to domestic and industrial pollution, the dissolved oxygen from tributaries, and the calculated value of the dissolved oxygen from re-aeration. It is difficult to calculate this latter figure accurately, because so many variables are involved. However, a value of 9000 lb. of dissolved oxygen per day per mile of stream was determined for conditions under which the 1948 tests were run. This figure is higher than most published re-aeration rates, but with the low D.O. saturation it may be somewhere

within the correct range. The curves show that in the 40 miles of river below the first point of heavy contamination, an organic load equivalent to approximately 450,000 lb. of oxygen per day has been added to the river. They also show that the B.O.D. and D.O. curves approached each other at the 40-mile point, indicating partial stream recovery at that point.

This, essentially, is the basic problem with respect to river conditions and some of the natural and man-made forces which were both for and against an easy solution to the problem.

**Manner of Approach.** The first step in setting up a stream abatement program was an attempt to evaluate the plant's contribution to the picture as a whole and to analyze the plant picture to determine what and where the most prevalent and troublesome contaminants were. To do this, it was necessary to identify all waste streams in the plant and to analyze these streams for their pollution value. The identification was easily done, although it developed a rather complicated picture, since a large part of the South Charleston plant is on an island in the river and the effluent is discharged through 35 major outfalls.

Evaluation of the industrial waste in these effluents as river pollutants was much more difficult.

For many years, the treatment methods for domestic wastes had been developing, and many methods of analysis had been devised to evaluate them. But when some of these tests were applied to industrial wastes, erratic results were obtained. The B.O.D. (Biochemical Oxygen Demand) determination, which turned out to be one of the most important, gave wide variations in results. In order to understand the standard test as applied to the wastes, a series of 50-day B.O.D. tests were

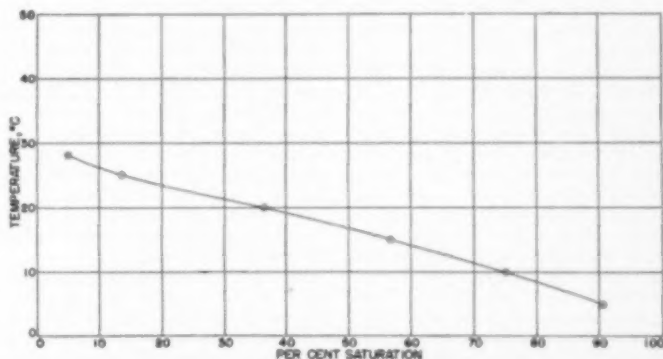


Fig. 1. Dissolved Oxygen Content Kanawha River Inlet South Charleston Plant Temperature vs. Per Cent Saturation



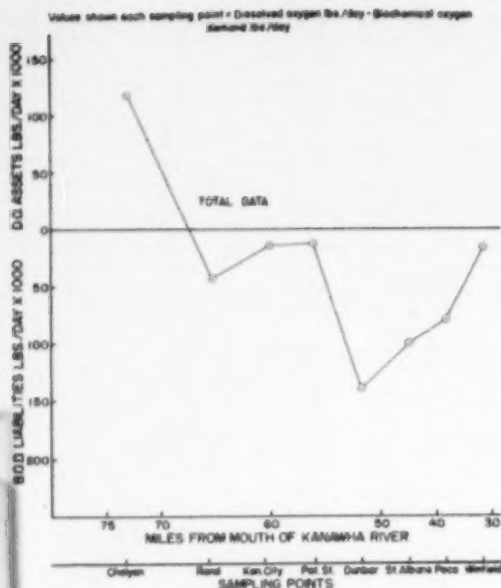


Fig. 2. Oxygen Balance—Low Flow

Kanawha River—Summer 1948  
West Virginia Water Commission

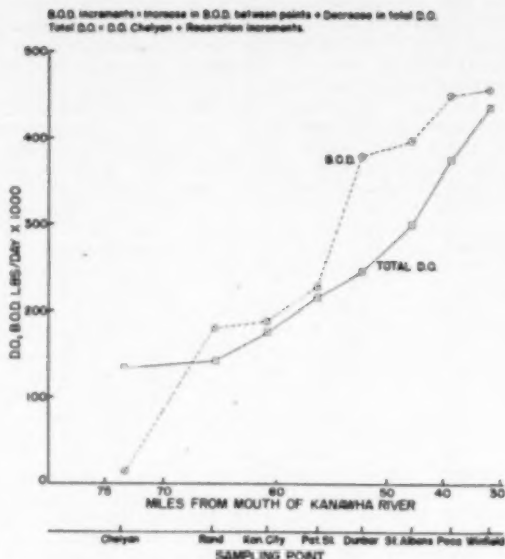


Fig. 3. Cumulative Biochemical Oxygen Demand and Total Available Dissolved Oxygen Relationship

Kanawha River—Summer 1948  
West Virginia Water Commission

run on a number of pure organic compounds. The tests were run on synthetic samples containing 2.5 p.p.m. of the organic under test. This low concentration was within the range which could possibly be present in the river and yet high enough to assure duplication of results. Several other dilutions were tried but discontinued after it was established that the 2.5 p.p.m. concentration was low enough to preclude any toxic effect on the biological action. All samples were seeded with settled sewage. Figures 4-7, which show time vs. per cent theoretical B.O.D., point up the inconsistency of results obtained by application of the standard test.

In Figure 4 it can be noted that methanol and ethanol have oxidized to approximately a 50% point in the standard 5-day period, while butanol-2 and the two glycols have shown little, if any, oxidation. At the end of 15 days, however, the butanol-2 curve has reached approximately the same point as the other alcohols. This is probably also true of ethylene glycol; the test samples were depleted of oxygen after 15 days incubation. Triethylene glycol oxidized to approximately the 12% point at the end of 40-days incubation.

Figure 5 gives about the same story, with acetone and butyraldehyde oxidizing rather rapidly, a delayed action with a rapid oxidation in the case of pro-

pylene glycol, and relatively no oxidation of isopropyl ether at the end of 50 days.

Figure 6 shows a rapid oxidation to about 60% of theoretical in monoethanolamine. Diethanolamine is not oxidized. Butyl amine reached about 50% at the end of 10 days and no further oxidation was obtained. Ethylenediamine is unreactive.

About the same picture is presented in Figure 7 with triethanolamine, methyl isobutyl ketone, isopropyl acetate and "Carbitol" acetate.

Results shown here certainly indicate that the standard B.O.D. test, which should give approximately 70% of the 20-day B.O.D. of domestic waste in a 5-day period, is not applicable to the evaluation of many industrial organic wastes. Six out of the 17 organic compounds tested gave results which were acceptable. No attempt was made to determine  $K$  values as it was evident that they would be of little value.

One of the most critical factors involved in the B.O.D. test is the dilution water used in the test.

Results obtained by three different types of dilution waters on samples of ethanol and butyraldehyde are shown in Table 1. Here again nothing definite appears, but mineralized dilution water may be the most suitable for the two chemicals which were tested. Use of bicarbonate water with butyraldehyde

gave the results one might expect.

These data established the fact that much more work will need to be done on the development of a satisfactory biological oxidation test for many of the industrial wastes. Tables 2 and 3 give the results obtained from a series of tests to compare the acid permanganate and the acid dichromate oxidation tests with the standard 5-day B.O.D. test in an effort to obtain some yardstick to evaluate the organic wastes. Here again 17 different organics were tested, but no trend acceptable for all organic compounds was indicated. The results which would be obtained from the oxidation of a combination of the organics tested, no doubt, would be different but cannot be anticipated.

**Methods Studied and Used in Plant Application.** The next step, which, of course, ran concurrent with the laboratory work, was the actual reduction of the pollution of the Kanawha River by the plant wastes. After thoroughly considering the various methods which would eliminate or reduce the amount of wastes to the river, the following three general classifications of these methods were evolved:

1. Those resulting in the elimination or reduction of wastes by changes of process, of equipment, or in operating conditions



- Those to effect recovery of the wastes if they could not be eliminated or reduced sufficiently
- Those of waste treatment if methods 1 and 2 are insufficient

Methods in class 1 normally have the most favorable economic aspects, but are the most complex and require the cooperation of all technical groups in the plant organization. The time element required to reconsider all plant processes, together with engineering design of equipment, is long, and progress in stream pollution abatement is consequently slow, but results are most favorable. An excellent example of its application was in a refining process of a highly aromatic residue which contained a large amount of cyclic dienes. Direct steam was used to supply heat for this distillation. The water layer which was continuously removed from the still kettle contained an emulsion of water and organic material which resisted all attempts at breaking and which had a high B.O.D., taste, and odor. A closed heating cycle was installed on the still kettle to eliminate the water phase and prevent formation of the emulsion.

Methods in class 2, or those of recovery with subsequent disposal, probably obtain quicker results than any of the others, and have been used most often to achieve rapid progress in pollution abatement. Separation of nonsoluble wastes, such as oils or floating or settleable solids, is the best example of this method. However, many of its applications are not so simple as this and may include any one or all of the following factors.

- Separation of large volumes of uncontaminated condenser waters from the waste streams to reduce the volumes handled in a recovery method and to maintain the waste concentration. Approximately 200,000,000 gal. of water are pumped per day, discharging a mixed effluent of approximately 193,000,000 gal. of uncontaminated cooling water and 7,000,000 gal. of waste waters. If a common waste recovery unit were installed, the separation of these streams would be necessary.
- Installation of separators for all non-soluble materials. One of the first moves was a complete survey of all plant processes to determine what insoluble materials could be easily

separated and collected for disposal by burning or other means. In many cases it required only the installation of a settling tank in which either a top or bottom layer could be drawn off. To facilitate separation, many usual aids such as temperature control and pH adjustment, were used. Emulsions may be often handled in this manner. In one of the chemical processes, a heavy residue is formed and discharged with a water stream at relatively high temperatures. A tank was installed to receive this waste stream and separate the organic residue prior to dumping it to the river. However, it was necessary to cool the stream to atmospheric temperature before sufficient organics would separate to give a good effluent. The organic material is burned in the steam plants after decantation.

- Installation of closed cycles on processing equipment helps concentrate waste materials. As mentioned before, in many distillation processes, heat for distillation is added in the form of direct steam. This means the production of an equivalent volume of water that must be condensed somewhere in the process. It will be contaminated with the organic under distillation and, if the volume of water is large, concentration of the organic material will be low and recovery difficult.

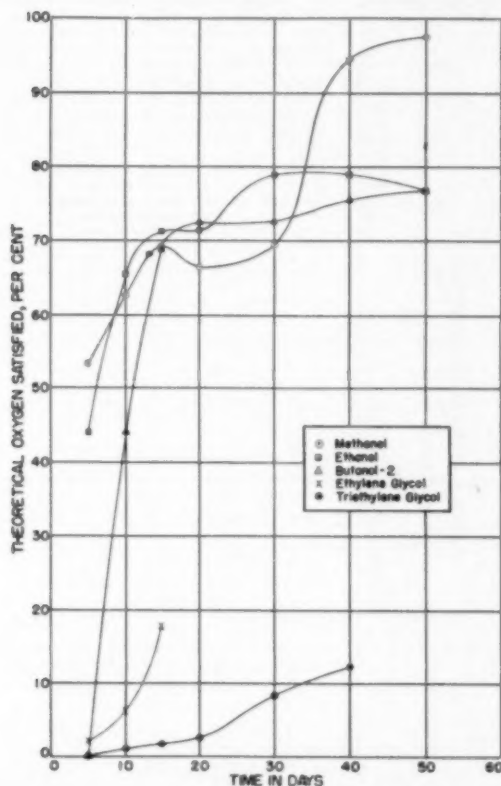


Fig. 4. Rate of Biochemical Oxidation of Organic Compounds

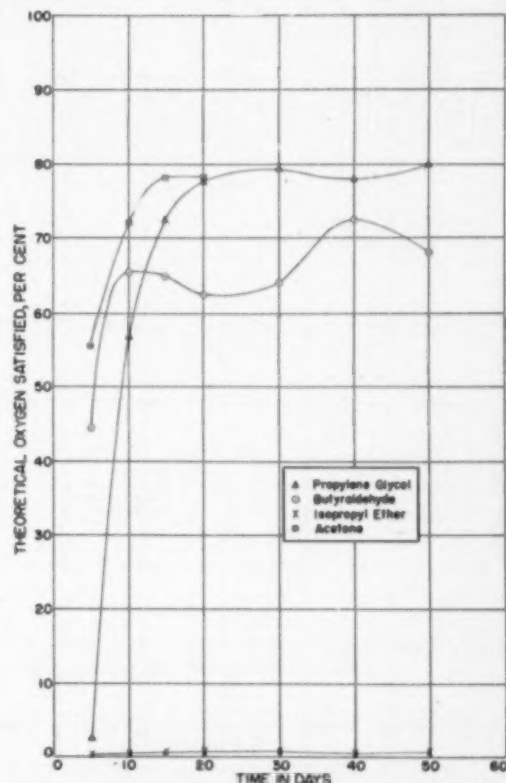


Fig. 5. Rate of Biochemical Oxidation of Organic Compounds

Table 1

BIO-CHEMICAL OXYGEN DEMAND  
EFFECT OF DILUTION WATER ON OXIDATION  
RATE OF ETHANOL AND BUTYRALDEHYDE

DAYS	ETHANOL		
	PER CENT OF THEORETICAL OXYGEN DEMAND SATISFIED		
	MINERALIZED WATER	BICARBONATE WATER	RIVER WATER
5	44.2	65.3	57.6
10	66.4	66.2	64.3
15	71.2	74.0	71.0
20	71.2	82.6	76.9

DAYS	BUTYRALDEHYDE		
	MINERALIZED WATER	BICARBONATE WATER	RIVER WATER
	MINERALIZED WATER	BICARBONATE WATER	RIVER WATER
5	44.3	12.3	55.7
10	65.6	26.2	57.4
15	64.8	23.9	66.6
20	62.3	11.5	34.4

With this in mind, all processes that make use of direct steam heating were studied. In several cases, closed heating systems were added to reduce the amount of the waste stream and to build up the concentration of wastes in the water phase to a point where it might be economical to recover the organic contaminant.

A good example of the application of this bottling-up process was in one of Carbide's units in which hot gases are quenched with water. In this process, a small amount of heavy, complex organic material is formed and condenses under normal conditions of temperature and pressure. This material is slightly soluble in

water and forms an emulsion with water. It imparts to the cooling water a high B.O.D. and taste and odor; it was one of the sources of water pollution first recognized back in 1935.

When a study was made of this condition shortly thereafter, it was found that it would be necessary to

Table 2

COMPARISON-BIO-CHEMICAL AND CHEMICAL  
OXIDATIONS OF ORGANIC COMPOUNDS

COMPOUND	PER CENT OF THEORETICAL OXYGEN DEMAND SATISFIED		
	ACID PERMANGANATE	ACID DICHROMATE	5 DAY B.O.D.
METHANOL	4.8	90.7	53.4
ETHANOL	4.0	38.4	44.2
BUTANOL-2	2.9	23.9	0.0
ETHYLENE GLYCOL	9.8	80.8	1.8
TRIETHYLENE GLYCOL	49.1	34.3	0.0
PROPYLENE GLYCOL	27.8	50.2	2.2
BUTYRALDEHYDE	5.5	11.5	44.3
ISOPROPYL ETHER	0.0	0.6	0.3
ACETONE	2.3	5.5	98.4

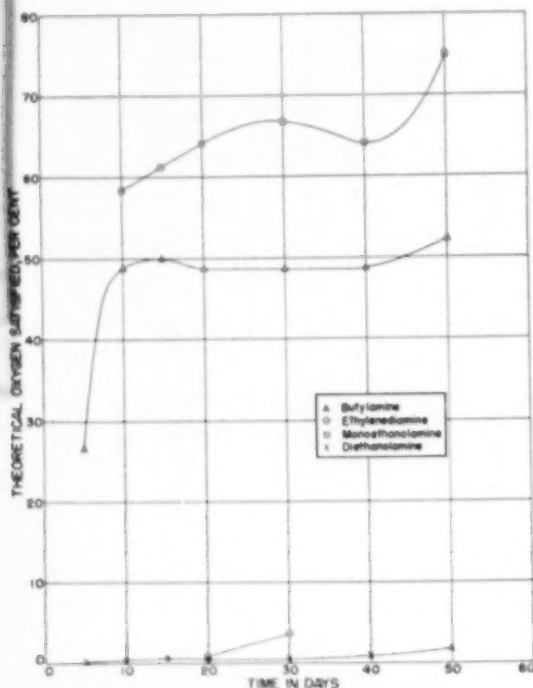


Fig. 6. Rate of Biochemical Oxidation of Organic Compounds

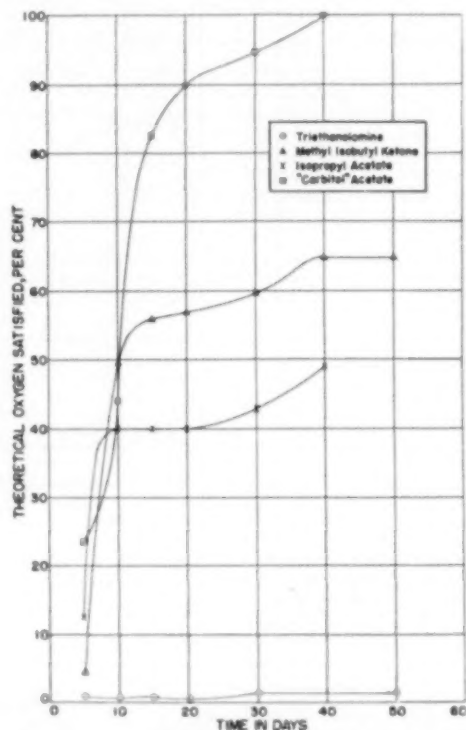


Fig. 7. Rate of Biochemical Oxidation of Organic Compounds

install a closed water-cooling cycle. This installation greatly reduced the pollution load from this source, but it was necessary to bleed off about 5% per day of the total volume of cycled water to prevent too great concentration of solids. The water removed from the system is now batch-treated with about 5 lb. of ferrous sulfate/M gal. and the clear liquid dumped into the river. The sludge is settled, dewatered and burned. The effluent from the cooling cycle prior to treatment with ferrous sulfate had 600 p.p.m. B.O.D. and a threshold odor of about 6400. The ferrous sulfate flocculation reduced the B.O.D. values to 60 p.p.m. and effected a 75% reduction in taste and odor threshold. The settled sludge contained 60% by weight of oil residues.

4. Use of waste material from one unit in another merits consideration in both production and waste disposal. This has many possibilities, probably the best example being the neutralization of acid and alkaline wastes.

At one of its operating units, Carbide has a waste containing large quantities of barium acetate and in another process waste sodium bisulfite. Both these materials have a high B.O.D. value. It was found that the admixture of the two prior to entering the river precipitates barium sulfite and reduced the total B.O.D. of the combined streams. Of course, the acetate radical is still present with its oxygen demand. In this case, both wastes are pumped into the fly-ash disposal line. This carries them to the fly-ash lagoons where the sulfite is allowed to settle. The effluent minus the settled-out products goes to the river along with the water used to transport the fly-ash.

5. What is to be done with the materials recovered? They are found in two forms—liquids and solids, and are normally complex mixtures of many organic substances. Work is continually going forward on the problem of separation and identification of the various components. Some of them may be returned for reprocessing while others may be marketable, if markets for their use can be developed. At the present time approximately 150,000 gal. per month of liquid residues are being burned. The solid wastes are either burned in an incinerator or hauled to a dump.

The third classification of methods are those in which the organic wastes cannot be recovered or disposed of by other means, and must be treated to render them innocuous. The results accomplished by these methods are more expensive, since little, if any, monetary return can be expected.

There are a number of general methods of treating organic wastes but, because of the extremely low concentrations, the choice of methods is limited. It is economically sound to make the maximum recovery or treatment before the waste is mixed with large quantities of water. The following methods of treatment are available and are being studied for application to the problem.

Table 3  
COMPARISON-BIO-CHEMICAL AND CHEMICAL  
OXIDATIONS OF ORGANIC COMPOUNDS

COMPOUND	PER CENT OF THEORETICAL OXYGEN DEMAND SATISFIED		
	ACID PERMANENTATE	ACID DICHROMATE	5 DAY B.O.D.
BUTYLAMINE	0.9	4.9	26.9
ETHYLENEDIAMINE	1.0	0.7	0.0
NONKETANOLAMINE	5.4	44.9	0.0
DIETHANOLAMINE	4.9	48.6	0.3
TRIETHANOLAMINE	15.2	37.2	0.7
METHYL ISOBUTYL KETONE	2.1	7.8	4.4
ISOPROPYL ACETATE	2.9	9.1	12.7
CARBOTOL ACETATE	0.9	46.6	23.1

1. Flocculation and sedimentation
2. Chemical precipitation
3. Biological oxidation (both aerobic and anaerobic)
4. Adsorption and absorption
5. Underground disposal

6. Chemical oxidation by use of chlorine, chlorine dioxide and ozone

The work to date indicates that chemical oxidation is a costly process, with poor results except in the treatment of

Values shown at each sampling point = D.O. lbs./day - B.O.D. lbs./day

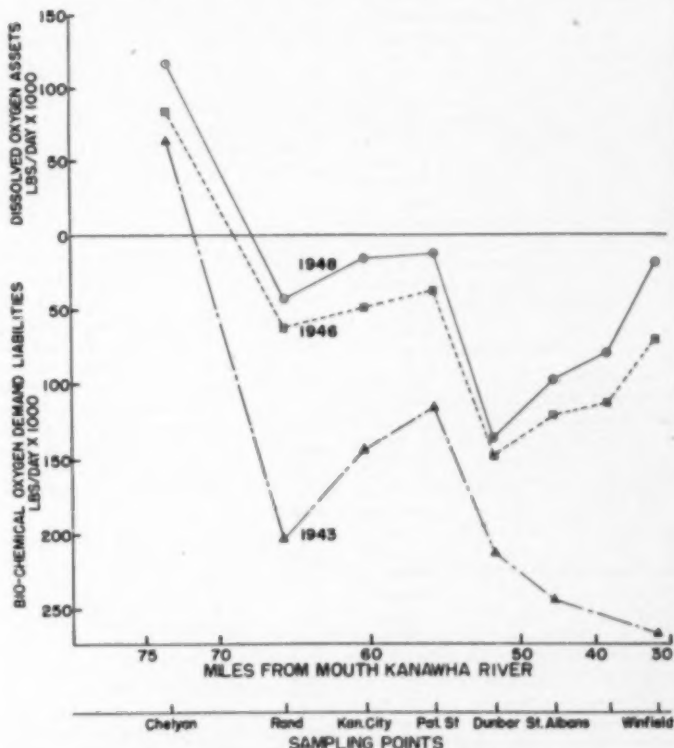


Fig. 8. Oxygen Assets and Liabilities Balance  
Kanawha River  
West Virginia Water Commission

a few specific organic chemicals. Use of biochemical oxidation will also be difficult because relatively large areas of ground are required for biofilters, aeration basins, and lagoons. However, we are still working on these approaches to the problem.

### Results

Figure 8 illustrates the oxygen balance curves on the Kanawha River for the years 1943, 1946, and 1948. This information was developed by the Water Commission of the State of West Virginia and indicates the improvement made during the various periods. As in several of the previous graphs the two points of heavy industrial loading are easily identified, one just below Cheyan and the Carbide plant just below the Patrick Street bridge. The most significant progress shown by this graph is the fact that in 1943 the oxygen balance continued to drop to Winfield, a point 25 miles below the Carbide plant site, while in both 1946 and 1948 the river began its recovery at a point about 2 miles below the Carbide plant. The rate of improvement was also more rapid in 1948 than 1946.

With these encouraging results already achieved, future developments will include continuation of this work as a part of an over-all program with the state and other industries. The aim of this and of similar pollution abatement programs conducted by neighboring communities and industries will continue to be the eventual improvement in the quality of Kanawha River water. Protection of public health, propagation and protection of aquatic life, and the industrial development of communities using water from the Kanawha River will in this way be greatly furthered.

### Discussion

**Anonymous:** Have you done any work with biofilters which would indicate that these compounds on which it is difficult to run a B.O.D. test, that is, which react slowly could be successfully treated by such biological processes?

**H. D. Lyon:** No, we haven't done any work with the biofilters on that basis. However, there are many factors that must be considered in determining the value of biofilters in disposing of these organic wastes. There is no doubt that a number can be successfully treated on biofilters while others would require unreasonably low rates of application.

**Anonymous:** It doesn't necessarily follow, because you have difficulty in oxidizing a chemical in a B.O.D. bottle, that it will not react on a filter where the filter more or less absorbs the or-

ganic from solution, to permit the bugs to go to work on it. The organic may be in the slimes of your filter for days and days, whereas the water goes through immediately. And I should think that some of these might respond, even though you can't get a good B.O.D. determination.

**H. D. Lyon:** This work was all done for test purposes, for evaluation purposes. It is probable that a more rapid oxidation would take place on a biofilter but again—the slower the reaction the larger the installation to handle equivalent amounts of organics. We have done no work with the biofilters.

**G. Gutzeit** (General American Transportation Corp., E. Chicago, Ind.): Our laboratories have made a series of determinations somewhat similar to your own, but on mixed wastes. We have found that the "oxygen consumed" (chemical oxygen demand, permanganate titration) is actually a better yardstick for judging the efficiency of a chemical treatment process than the standard B.O.D. figure. However, the results of these two analytical tests do not seem to bear any definite relationship. The ratios C.O./B.O.D. with our type of waste range generally from 0.34 to 4.8, with some maxima over 10.5. As only the B.O.D. value is pertinent for estimating the ability of a receiving stream to handle the pollution load, these analytical data have to be used for judging final treatment results, despite their drawbacks and uncertainty in the case of complex industrial wastes. On the other hand, for laboratory and development work, C.O. values represent as good if not a better gauge for determining the efficiency of a chemical treatment method.

**F. W. Mohlman** (Sanitary District of Chicago, Chicago, Ill.): The 450,000 lb. of B.O.D. in the river—what was the river flow in cubic feet per second at that time? Also, with reference to the B.O.D. determination, were they seeded, and did you have about four or five different dilutions of each sample? That is, I wouldn't want to think you used just one.

**H. D. Lyon:** The flow of the river at the time of 450,000-lb. loading was about 1500 ft./sec. We did run two different dilutions on the various chemicals. However, additional dilutions were started to establish trends. The dilutions were sufficiently low to preclude any serious toxic effect.

**J. V. D. Hardy** (Du Pont Co., Wilmington, Del.): Would you care to say anything about Carbide's experience with underground waste disposal?

**H. D. Lyon:** We don't have any ex-

perience. It is one of the factors under consideration. I hope that I didn't mislead people into thinking that we are at the present time actively engaged in that method of disposal. That was a listing of methods which we will consider. We have absolutely no experience in underground waste disposal.

**L. F. Warrick** (U. S. Public Health Service, Washington, D. C.): Did you use seeding in making the oxygen demand determinations with these samples? What was the procedure?

**H. D. Lyon:** We used seeding in all those tests.

**W. W. Hodge** (Mellon Institute, Pittsburgh, Pa.): Regarding the drop in the second set of curves, does that include all the effects of sewage discharged to the river from Charleston and vicinity or is it limited just to the effluents from the chemical plants? In the oxygen balance curve after the first drop there was a little recovery and then there was a second steep drop. Is that caused by the untreated sewage from Charleston?

**H. D. Lyon:** That is right.

**W. W. Hodge:** If you have waste liquors which have no 5-day B.O.D. such as shown in several of the figures, would there be any object in treating them in a biological process where the time of throughput would be about 6 or 8 hours? Maybe Dr. Mohlman can tell us about that. What good results are accomplished by treating materials which do not have any 5-day B.O.D., in a biological filter?

**F. W. Mohlman:** I am just a little disappointed that you used only two dilutions. I think you have to use quite a number of dilutions to get beyond or out of the range of toxicity of wastes, and to the range where you can get something from those determinations. So there is always some doubt whether they indicate the effect the waste will have if handled on antibiological filters. I really think the proof of the pudding will be that river determination. Some of them may have and some of them may not have, but the river is the proof of the discharge, and you have to go on that basis.

**H. D. Lyon:** An attempt to get good results, or let's say accurate results on river surveys is a tough problem, with the flows changing every hour or so by the operation of power dams. And I think part of this work, although it hasn't been carried far enough, will explain some of these peculiar results we have gotten in a number of river surveys. I can't be sure yet because the work hasn't been carried far enough, but I believe it will.

(The End)

# POWER CHARACTERISTICS OF MIXING IMPELLERS

## PART I

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Mixing Equipment Company, Rochester, New York

The common forms of impellers used for agitation and mixing of liquid systems have been studied under conditions existing in laboratory and large-scale operations. Correlations of the most important variables are presented in the form of dimensionless groups, characteristic plots, and general equations.

Properties of the impeller, tank, and fluid have been studied over wide ranges of power, size, and physical properties. Data are given on Marine-type three-blade propellers; paddles; flat, curved, and arrowhead blade turbines; fan turbine; and a curved-blade turbine with shrouding. Propeller sizes range from 3 in. to 20 in. diameter; turbines from 3 in. to 48 in. Tanks were vertical, cylindrical, flat bottomed, used in five sizes from 8.5 to 96 in. diameter. Tanks were used without baffles and with four vertical wall baffles sized up to 17.7% of tank diameter. Fluid viscosities were varied from approximately 1 to 40,000 cp., and power measurements were made from 0.001 to 8 hp. Correlations in terms of Reynolds number extend from 1 to 1,000,000.

**I**MPELLERS of many types are used to produce agitation and mixing in the liquid phase. To produce mixing it is necessary to supply energy, and this is usually accomplished through the rotation of an impeller. The rate at which energy is supplied, or the power, is not only dependent upon the type impeller used and how rapidly it is rotated but also on the physical characteristics of the fluid, and shape of the container, and the relative location of all component parts of the system such as baffles, coils, and supports. Hence, to characterize the behavior of any impeller it is necessary to take into consideration the complete environment in which it operates.

When an impeller is turned in a fluid contained in a vessel, movement of the

fluid and eddy currents are produced. Once this flow pattern is established due to the impeller, fluid, and tank, the only change in energy input that can be impressed on the system is by virtue of a change of speed of turning, or rotation, of the impeller. For this reason it is customary to say that power is demanded by, or drawn by, the impeller; and, regardless of the capacity of the motor or other mechanism supplying energy, the demands of the impeller, due to its speed of rotation and to its environment, control the power used in the mixing operation. Such power demands or responses are used to characterize various impellers in relation to the environments in which they may operate.

Many workers have studied the effect of moving solid bodies through fluids. In the late nineteenth century Unwin (17) and others rotated discs and other shapes in air, and later numerous experiments were performed to determine the resistance to motion of many shapes of solids through water. The so-called drag and the power required to overcome it have been determined for ship hulls and air-plane structures moving through fluids,

and also for fluids moving through various channels of solid materials. In common with the well-substantiated methods of analysis and correlation of factors involved in fluid dynamics for the systems just mentioned, it is possible and convenient to treat the study of the behavior and characteristics of mixing impellers by the same methods.

White (18) and his co-workers were the first to point out the possibility and advantage of correlating the performance of mixing impellers by the use of dimensional analysis and a study of models. Hixson (6) and his colleagues made further theoretical analyses and also gave substantiation to the theory by experimentation. Other experimental data have been reported (9, 10, 13, 16). There are review articles (5, 7, 8, 10) comparing published data on the power absorption of mixing impellers, but there are few if any comprehensive data covering wide ranges of conditions such as are encountered in industrial mixing operations. An extensive research program was initiated some years ago by the Mixing Equipment Co., Rochester, N. Y., to establish the characteristics of various types of impellers used commercially for agitation and mixing operations in liquid systems. Data here presented are a result of this work.

### Theoretical Considerations

The motion of a fluid can be defined in terms of length, time, mass, and force, for which **L**, **T**, **M**, and **F** are used for notation. These are the four fundamental dimensions of mechanics. English units to be used are: foot for length, second for time, slug for mass and pound for force. Newton's second law of motion involves all four dimensions, and in terms of force it is expressed as

$$F = Ma$$

† Also Illinois Institute of Technology, Chicago, Ill.

NOTE: Table 2, Summary of Experimental Operations, and Table 7, Data on Flat Six-Blade Turbines, 10% Baffles, are on file (Document 2860) with the American Documentation Institute, 1719 N Street, N.W., Washington 6, D. C. Data can be obtained by remitting 50 cents for a microfilm and 50 cents for photoprints.



TABLE I—NOTATION  
Variables Studied and Groups Used for Correlations

Symbol	Definition and Dimension	Dimensionless Group or Ratio in Which Used	Exponential Function for the Group or Ratio
$P$	Power, ft.lb./sec.	$Np$	
hp.	Horsepower, $P \div 550$	$Np$	
$N$	Impeller speed, rev./sec.	$Np$ $Np$ $Np$	$n$
$\rho$	Density of fluid, slug/cu.ft. or lb. mass/cu.ft.	$Np$ $Np$ $Np$	$m$
$\mu$	Viscosity of fluid, lb. mass/ft. (sec.)	$Np$	$m$
$\nu$	Viscosity, kinematic, sq.ft./sec.	$Np$	$m$
$g$	Gravitational constant, ft./sec. (sec.)	$Np$ $Np$	$n$
$D$	Impeller diameter, ft.	$Np$ $Np$ $Np$	$m$
		Also in most of the following	
$T$	Tank diameter, ft.	$T/D$	$t$
$H$	Liquid depth, ft.	$H/D$	$h$
$C$	Height of impeller off bottom, ft.	$C/D$	$c$
$B$	Number of baffles	$B/A$	$b$
$J$	Width of baffles, ft.	$J/D$	$j$
$S$	Pitch of impeller	$S/D$	$s$
$B$	Number of blades on impeller	$B$	$b$
$L$	Length of impeller blades, ft.	$L/D$	$l$
$W$	Width of impeller blades, ft.	$W/D$	$w$
$Nr$	Froude number	$DN^2/g$	$n$
$Np$	Power number	$P/gD^3$	
$NRe$	Reynolds number	$DN\mu$ $\rho$	$m$
$F$	Force, lb.		
$L$	Length, ft.		
$M$	Mass, slug, ( $F/a$ )		
$T$	Time, sec.		
$a$	Acceleration, ( $L/T^2$ )		
$\phi$	A function, either $Np$ or $Np/(Nr)^n$		

where  $a$  is acceleration ( $L/T^2$ ), hence

$$F = \frac{ML}{T^2}$$

Thus, mass and force are related by length and time, and it is possible to reduce to three the number of fundamental dimensions essential to describe a fluid motion. That is, the dimensions of mass, length, and time ( $M-L-T$ ), or the dimensions of force, length, and time ( $F-L-T$ ), may be used.

The properties of a fluid, such as weight, density, viscosity, surface tension, and the like may also be defined by the same dimensions of  $M-L-T$  or  $F-L-T$ .

The geometric form of a fluid is fixed by the solid or moving boundaries and is defined in terms of length.

Table I shows a number of variables encountered in mixing, together with notation symbols and fundamental dimensions.

### Mechanics of Similitude

Since fluid motion, fluid properties, and boundary conditions can be de-

scribed in the same dimensional units, it should be possible to relate them so that similar fluid flow motion in two different boundaries, or with two different fluids, could be related to each other. Such a technique is used to show similitude of the mechanics of fluid motion (12).

The principles of similitude are of considerable use in delineating dynamic occurrences. It is of interest here to consider only certain principles as applied to fluid motion in a mixing tank. No doubt perfect similarity of motion is rarely achieved between two systems, but a close approach to similarity is often sufficient for practical problems, and the mathematics derived from dimensional analysis of similitude can be used to scale-up pilot plant or other operations.

There are three types of similarity:

**Geometrical similarity** involves form or shape only. Geometry is similar when corresponding dimensions have the same ratio as all other corresponding boundary dimensions.

**Kinematic similarity** means similarity

of motion. Motion occurrences are similar if the patterns or paths of motion (the fluid regime) are alike, and if the velocities at corresponding points have the same ratio as velocities at other corresponding points. Geometrical similarity is inherent in kinematic similarity.

**Dynamic similarity** refers to masses and forces. Two motions are dynamically similar if they are kinematically similar, if the ratios of masses at corresponding points are equal, and if the ratios of forces at corresponding points are equal to those at other corresponding points.

**Dimensional Analysis for Mixing.** Variables which affect fluid motion in mixing are of three types.

First, the linear dimensions which fully define the geometrical boundary conditions and shape for the tank and impeller such as (see Table I):  $D$ ,  $T$ ,  $H$ ,  $C$ ,  $S$ ,  $L$ ,  $W$ ,  $J$ . Also,  $B$  the number of blades and  $R$  the number of baffles help to describe shape of impeller and tank wall but are not here related to  $F-L-T$ , but rather simply to a reference number.

Second, the fluid properties such as density and viscosity.

Third, the kinematic and dynamic characteristics of flow such as velocity, power input or resisting forces, and the force of gravity. The velocity of flow can be considered as a function of the velocity of the tip of the impeller, or  $\pi DN$ , and the velocity is proportional to  $N$ , the revolutions per unit time of the impeller. The power input by the impeller,  $P$ , is used to produce the forces in the mass flow and also to overcome the force of gravity,  $g$ .

In order to analyze fluid motion by the fundamental dimensions of  $F-L-T$ , a technique was developed by Buckingham (4), which is called the Pi theorem. Another method proposed by Rayleigh (11) may also be used to give the same results (3). The Pi theorem states that if one variable (for example, power,  $P$ ) depends upon a number of independent variables (for example, those listed above which define boundary, kinematic, and dynamic conditions), they may be expressed in a general functional relationship such as

$$f(D, T, H, C, S, L, W, J, \rho, \mu, g, N, P) = 0 \quad (1)$$

Further, if these thirteen variables can be given in terms of three of the fundamental dimensional units ( $F-L-T$ ), the equation can be expressed as a function of  $13-3$ , or ten dimensionless  $\pi$  terms, and each such term will have  $3+1$ , or four variables, only one of which need be changed from term to



term. To be dimensionally homogeneous each term must contain identical powers of each dimension. It is convenient to choose a length, a velocity, and the density for three of the four variables of each term and to use the remaining ten variables, with an exponent of -1, separately in the ten  $\pi$  terms. Thus, the general equation becomes:

$$f'(\pi_1, \pi_2, \pi_3, \dots, \pi_{10}) = 0$$

Using impeller diameter  $D$  for the characteristic or reference length, the impeller speed  $N$  for velocity, and  $\rho$  for the fluid density, the values of the  $\pi$  terms can be evaluated as follows:

$$\pi_1 (\text{for tank diameter } T) \\ = D^3 N^3 \rho^3 T^{-1}$$

substituting dimensions and solving:

$$\pi_1: L^3 \left( \frac{1}{T} \right)^3 \left( \frac{FT^2}{L^4} \right)^3 T^{-1} = L^0 T^0 F^0$$

$$L: x - 4z - 1 = 0$$

$$T: -y + 2z = 0$$

$$F: z = 0$$

whence

$$\left. \begin{aligned} z &= 0 \\ y &= 0 \\ x &= 1 \end{aligned} \right\} \text{thus } \pi_1 = \frac{D}{T}$$

It will be evident that if two variables of like dimension appear together in a group, the other variables disappear, hence  $\pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7$  may be written by inspection as:

$$\frac{D}{H}, \frac{D}{C}, \frac{D}{S}, \frac{D}{L}, \frac{D}{W}, \text{ and } \frac{D}{J}$$

respectively,

$$\pi_8 (\text{for } \nu) = L^3 \left( \frac{1}{T} \right)^3 \left( \frac{FT^2}{L^4} \right)^3 \left( \frac{L^2}{T} \right)^{-1} \\ = L^0 T^0 F^0$$

$$L: x - 4z - 2 = 0$$

$$T: -y + 2z + 1 = 0$$

$$F: z = 0$$

whence

$$z = 0$$

$$y = 1$$

$$x = 2$$

$$\text{thus } \pi_8 = \frac{D^2 N}{\nu}$$

In a similar fashion

$$\pi_9 = \frac{DN^2}{g}$$

and

$$\pi_{10} = \frac{D^3 N^3 \rho}{P}$$

In addition to these ten  $\pi$  terms there are two other number ratios that can be used to include the variables of number of blades  $B$ , and number of baffles  $R$ . These may be written as

$$\left( \frac{B}{No.} \right) \text{ and } \left( \frac{R}{No.} \right)$$

$$N_P = K (N_{Re})^a (N_{Fr})^b \left( \frac{T}{D} \right)^c \left( \frac{H}{D} \right)^d \left( \frac{C}{D} \right)^e \left( \frac{S}{D} \right)^f \left( \frac{L}{D} \right)^g \left( \frac{W}{D} \right)^h \left( \frac{J}{D} \right)^i \left( \frac{B}{No.} \right)^j \left( \frac{R}{No.} \right)^k \quad (3)$$

The reference number  $No.$  being determined by convenient choice. Combining all the groups, the following significant relationship can be written

$$f' \left( \frac{D}{T}, \frac{D}{H}, \frac{D}{C}, \frac{D}{S}, \frac{D}{L}, \frac{D}{W}, \frac{D}{J}, \frac{DN^2}{\nu}, \frac{DN^2}{g}, \frac{D^3 N^3 \rho}{P}, \frac{B}{No.}, \frac{R}{No.} \right) = 0 \quad (2)$$

All terms are dimensionless when consistent units are used.

This relationship contains three basically different parameters: those defining the boundary conditions and shape (the first seven terms and the last two); those pertaining to the action of viscosity and gravity; and that which characterizes the general flow pattern.

The boundary conditions are defined by simple length or number ratios.

The two terms characterizing the force of viscosity and of gravity have been given particular names, the Reynolds number  $N_{Re}$  and the Froude number  $N_{Fr}$ :

$$N_{Re} = \frac{DN}{\nu}$$

and since

$$\nu = \mu/\rho$$

$$\text{it may also be written } \frac{D^2 N \rho}{\mu}$$

$$N_{Fr} = \frac{DN^2}{g}$$

The term  $\frac{D^3 N^3 \rho}{P}$  characterizes the basic flow pattern. It is convenient to invert it so that power appears in the numerator and then to call it the power number  $N_P$ . In addition, it must be noted that the density  $\rho$  was used in force units in the derivation, and the term is dimensionless as derived. However, it is customary in the chemical engineering literature to use  $\rho$  as lb. mass/cu.ft., rather than the force unit of slug/cu.ft. Therefore, by dividing  $\rho$  in lb./cu.ft. by  $g$  (32.2 ft./sec.<sup>2</sup>) the power number can be written

$$N_P = \frac{Pg}{\rho N^3 D^3}$$

where  $\rho$  has the units of lb. mass/cu.ft.

Any of the  $\pi$  terms can be considered as the dependent variable in the general equation, but it has been found that the power number contains the essential characteristics of the flow and is therefore used as the dependent variable. Further, it is most convenient to use  $D$  in the denominator in the dimension ratios, thus Equation (2) can be written:

This is the general equation relating the physical variables most often encountered in mixing with a single impeller, centered in a cylindrical, vertical

axis, flat-bottomed tank. The equation can be expanded to account for other tank shapes, bottom shapes, impeller positions not coincident with the axis of the tank, for multiple impellers, and other such variables. When a sufficient amount of experimental evidence is at hand to evaluate the functional relations indicated by the exponents, it is possible to predict behavior of fluid motion and forces involved, and to account for power input for operations carried out in pilot plant models and large-scale operations. Data and correlations here reported give some information on each variable shown in the equation.

Equation (3) is shown in exponential form. This is for convenience in notation. Values of the exponents have been determined over wide ranges in some cases and over limited ranges in others. Occasionally the exponents are constant over wide ranges of data, and in some cases they vary continuously over the range of data. However, no more simple correlation has as yet been achieved, and this one does lead to important generalities and to useful ends.

### Significance of General Equation of Flow

The last nine terms of Equation (3) define geometric boundary conditions which affect fluid motion. They are the parameters of geometric similarity. If they remain fixed for any one set of experiments, it is possible to simplify the equation and to write

$$N_P = K (N_{Re})^a (N_{Fr})^b \quad (4)$$



Fig. 1. Small Dynamometer

This allows evaluation of the variables occurring in the groups in this equation. Conversely, if the Reynolds and Froude numbers are kept constant or negligible, each of the boundary parameters may in turn be evaluated.

The Reynolds and Froude numbers are parameters which describe kinematic conditions. The Reynolds number accounts for the effect of viscosity when viscous forces are dominant. When viscous forces control, kinematic similarity cannot exist unless the Rey-

nolds number has the same value in the two flow situations being compared. The Froude number accounts for the force of gravity when it plays a part in determining the motion of the fluid. Froude numbers must be equal to have similar flow when gravity forces control the motion. If both gravity and viscous forces play important roles (as is the case when a vortex exists in a mixing operation), then both the Froude and the Reynolds numbers must be kept constant when comparing a pilot plant, or model, operation with a prototype (14).

To present data graphically it is convenient to use the Reynolds number as abscissa in logarithmic plots. This is the usual technique in presentation of fluid dynamic data (1). It is followed here for convenience and to emphasize that motion in a mixing tank is capable of analytical treatment in the same fashion as other flow occurrences. To arrive at a convenient form, Equation (4) can be written

$$\phi = \frac{N_p}{(N_{Re})^a} = K(N_{Re})^m \quad (5)$$

And for many cases where  $(N_{Re})^a$  is equal to 1 or its effect is negligible:

$$\phi = N_p = K(N_{Re})^m \quad (6)$$

The great majority of all mixing operations in industry can be handled by this equation. It has been found that

the most useful correlations of impeller performance and its effect on mixing can be made by plotting  $\phi$  or  $N_p$  vs.  $N_{Re}$  on log-log coordinates using various boundary dimension parameters (see Fig. 15).

To correlate performance in terms of power, Equation (6) may be expanded and written:

$$P = \frac{K}{g} \rho N^2 D^5 \left( \frac{D^2 N \rho}{\mu} \right)^m \quad (7)$$

Equations (4) and (7) can be used to characterize impellers in different environments because they describe dimensional and dynamic similarity. A characteristic curve of a plot of the equation will result. It will be shown later that three characteristic points can be used to define this characteristic curve.

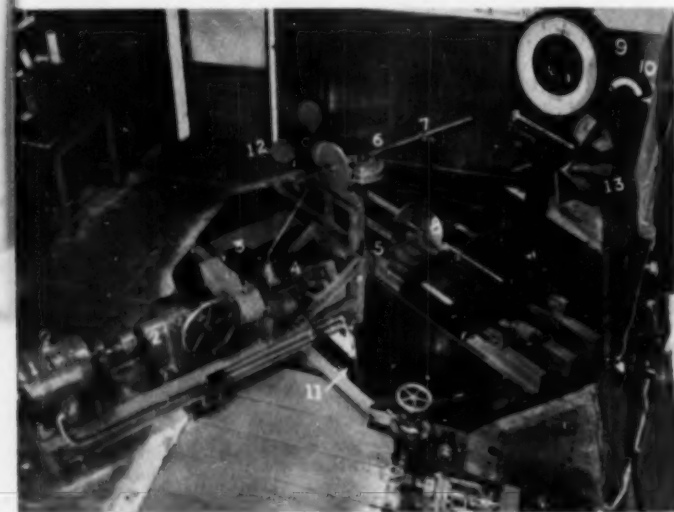
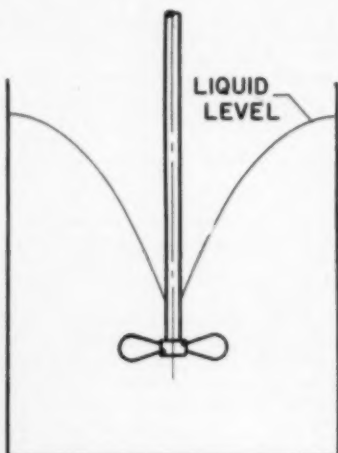
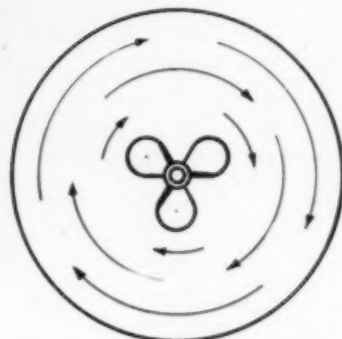


Fig. 2. Large Dynamometer

1. A.C. Motor—Single Speed.
2. Master Electric-Vario Drive.
3. Magneto (2 speed) for Tachometer.
4. Gear Box, 4 speeds.
5. Differential.
6. Torque Arm.
7. Knife Edges.
8. Adjustable Angle Bell Crank.
9. Scale.
10. Tachometer.
11. Impeller Shaft Connected with Coupling.
12. Marine-type Propeller.
13. Fan Turbine.



SIDE VIEW



BOTTOM VIEW

Fig. 3. Fluid Flow Pattern for Any Shape Impeller When No Baffles Are Used

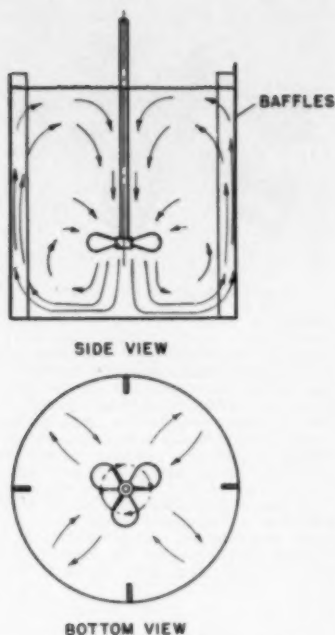


Fig. 4. Fluid Flow Pattern for Propellers When Baffles Are Used

#### Experimental Equipment

Data for the experimental work were obtained from six different-sized vertical cylindrical flat-bottomed tanks. Tanks of 8.5, 13 and 18 in. in diameter were made of either transparent plastic or glass. Tank sizes of 36, 54, 96 in. diameter were made of iron. In all cases tank depth was greater than tank diameter.

Power was measured by means of dynamometers. For the smaller tank sizes the dynamometer consisted of a variable-speed constant-torque motor mounted on a set of ball bearings and attached to a circular plate, so that the radius of the plate acted as a torque arm. The plate carried a flexible cable which passed over a pulley to a dial-type scale. The mounting of the motor torque arm and bearings was hinged in such a way that the torque cable passed through the centerline of a hinge. In this way it was possible to tilt the dynamometer to any desired angle in the vertical plane and still measure torque. The motor was equipped

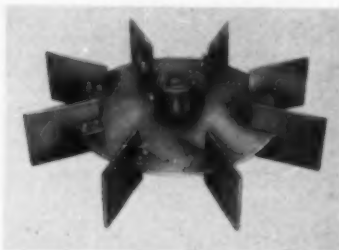


Fig. 7. Flat Blade Turbine

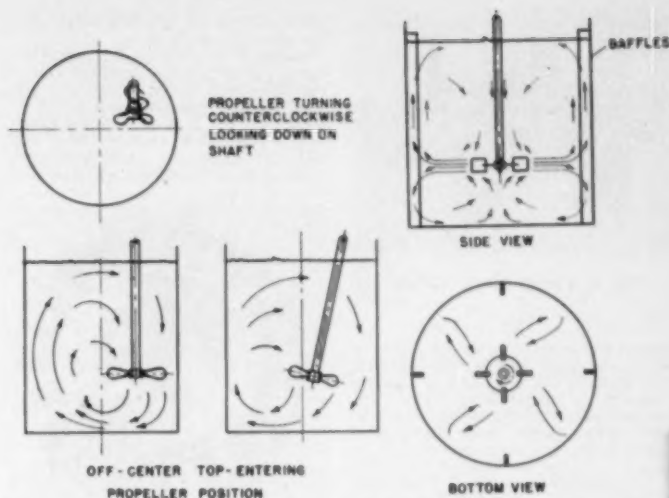


Fig. 5. Fluid Flow Pattern for Propellers in Off-centered Position

Fig. 6. Fluid Flow Pattern for Turbines with Baffles

with a hollow shaft and coupling so that various lengths of shafts could be inserted and various impellers attached to the end of the inserted shaft. This allowed wide variation of impeller position. Speed measurements were made by means of an electrical tachometer attached to the hollow motor shaft. This small dynamometer was carefully calibrated and was useful over a wide range of speeds and for power ranging from 0.001 hp. to approximately 0.25 hp. A photograph of the dynamometer with weight

scale and tachometer is shown in Figure 1. The dynamometer is shown carrying a shaft with impeller for operation in the 13-in. diameter plastic tank. The photograph shows four baffles located at the walls of the tank.

For larger-sized tanks a differential-type automotive dynamometer was used, torque was measured on platform scales and an electrical tachometer was mounted on the shaft. A photograph of this dynamometer is shown in Figure 2 with an impeller shaft

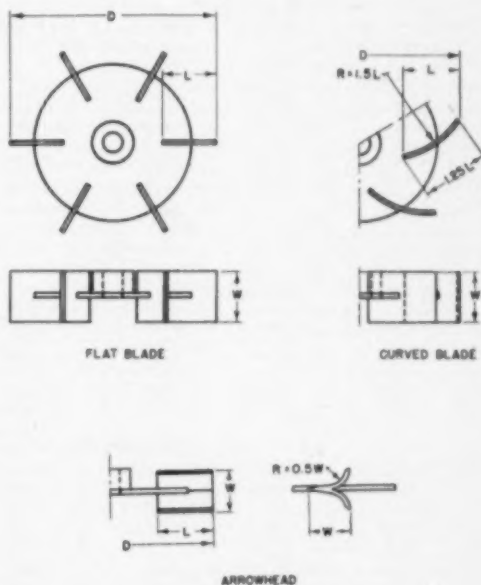


Fig. 8. Turbine Dimensions



Fig. 9. Curved Blade Turbine

attached and mounted in the 8-ft. diameter tank located in the floor of the laboratory. This dynamometer was used to measure powers up to approximately 8 hp. The dynamometer set-up also shows one of the four vertical baffles used. These were wooden baffles extending from the top of the tank to the bottom, attached to the tank wall by means of C-clamps. All baffles were vertical.

The significant baffle dimension referred to as baffle width is measured along a diameter of the tank. The thickness of baffles used in the small tanks was approximately  $\frac{1}{8}$  in., whereas the thickness of

baffles used in the two larger-sized tanks was either  $1\frac{1}{4}$  or  $2\frac{1}{4}$  in.

Various kinds and sizes of impellers were studied. There are in general two types of impellers—those which produce essentially axial flow when operating in a baffled condition (15), and those which produce essentially a radial flow when operating under baffled conditions. It is necessary to specify baffled conditions, because an impeller of

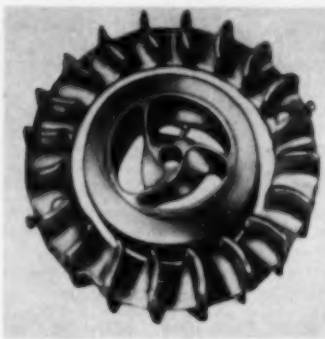


Fig. 11. Shrouded Curved Blade Turbine with Stator Ring

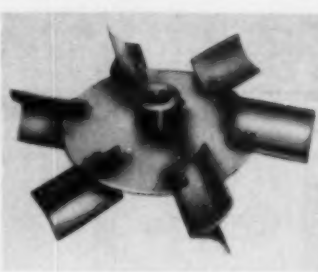


Fig. 10. Arrowhead Turbine

any shape operating on a vertical centerline of a smooth-walled unbaffled cylindrical tank will produce rotary and circular laminar flow, resulting in swirl and the minimum of vertical flow currents (see Fig. 3).

Figure 2 item 12, shows the typical 3-blade marine-type propeller which is commonly used in many mixing operations. Propellers in baffled conditions produce axial flow, as illustrated in Figure 4; propellers of six different pitches were used. These were operated so that fluid was discharged downward from the propeller toward the tank bottom. Data were taken for

TABLE 3.—THREE-BLADE MARINE-TYPE PROPELLER, 12-IN. DIAMETER, 11.8 IN. PITCH, 12 IN. ABOVE TANK BOTTOM, TANK DIAMETER 54 IN., LIQUID DEPTH 54 IN.

Liquid		Impeller		$\frac{NRe}{DN^2}$	$\frac{NFr}{DN^3}$	$\frac{Np}{\rho N^3 D^5}$	$\eta$	$\frac{\phi}{NFr}$
Density lb./cu. ft.	Viscosity lb./ft. sec.	Speed N rev./sec.	Power P ft. lb./sec.					
No Baffles in Tank								
89.82	28.8	1.00	39.3	3	0.031	14.10		
89.82	27.1	6.66	2030.0	22	1.350	2.45		
89.57	11.26	1.25	27.9	10	0.048	4.22		
89.57	11.19	10.00	3245.0	80	3.105	1.168		
88.01	2.67	1.66	19.5	55	0.086	1.465		
88.01	2.665	6.66	577.0	220	1.380	0.711		
86.51	0.633	4.16	93.0	568	0.540	0.477	0.153	0.434
86.51	0.633	6.66	337.0	910	1.380	0.422	0.164	0.445
83.95	0.137	5.83	175.0	8,860	1.057	0.338	0.199	0.342
78.21	0.0169	4.16	60.0	17,250	0.540	0.375	0.335	0.325
78.21	0.0169	7.50	274.0	51,000	1.743	0.268	0.349	0.306
62.42	0.000733	1.66	5.23	141,800	0.086	0.584	0.286	0.269
62.42	0.000733	8.33	246.0	709,000	2.155	0.220	0.325	0.282
Four Baffles, Each 8.2% Diameter								
89.5	7.94	3.33	189.5	37		1.83		
89.5	7.89	10.00	2740.0	113		0.967		
88.0	2.60	3.33	101.4	113		1.00		
88.0	2.59	11.69	2550.0	397		0.586		
86.5	0.568	6.68	350.0	1,018		0.437		
84.0	0.1263	6.60	130.5	3,280		0.400		
77.5	0.0171	8.33	462.0	37,600		0.334		
62.4	0.000733	6.68	183.0	576,000		0.318		
62.4	0.000733	11.69	1022.0	1,066,000		0.332		
Four Baffles, Each 10% of Diameter								
89.5	7.50	1.67	33.0	19		2.71		
89.5	7.45	3.00	468.0	60		1.39		
88.0	2.78	3.33	106.1	105		1.04		
88.0	2.74	12.51	2340.0	402		0.604		
86.5	0.662	8.33	700.0	1,090		0.447		
84.0	0.1400	4.17	79.7	2,500		0.432		
78.2	0.0170	5.00	120.0	23,000		0.346		
78.2	0.0169	11.67	1261.0	59,600		0.329		
62.4	0.000639	5.00	780.0	473,000		0.327		
62.4	0.000639	11.67	1055.0	1,103,000		0.344		

their operation with and without baffles and also in the "off-centered" position (Fig. 5).

The fan-type turbine shown in Figure 2 item 13, is also an axial-flow type; two different sizes were used containing 6 and 8 blades with the blades set at a 45° angle to the shaft and rotated for downward discharge.

Four different styles of radial flow turbines were used. The flow pattern for radial flow impellers when baffles are used is illustrated in Figure 6. The flat-blade turbine illustrated in Figure 7 was used in 21 different diameters from 3 to 48 in. Turbine dimensions are given in Figure 8. The standard ratios for the dimensions are  $D:L:W = 20:5:4$ . Various numbers of blades from 3 to 12 were used. Some runs were made without baffles, but the majority of runs were made under baffled conditions.

One curved-blade turbine illustrated in Figure 9 was tested, and four different diameters of arrowhead blade (dispenser) turbines (Fig. 10) were used. These turbines were operated both with and without baffles. A shrouded turbine shown in Figure 11 was operated with a stator ring and without other baffles, and also with wall baffles without the stator ring. Four different diameter paddles (from 4 to 42 in.) were used. These were simple 2-blade flat paddles having blades from 1 to 7 in. in width.

In most operations the impellers were placed one impeller diameter above the bottom of the tank, but impeller location was varied between 0.5 and 1.2 impeller diameters above tank bottom.

### Liquids Used

Water, kerosene-carbon tetrachloride mixtures, lubricating oil, linseed oil and various corn syrup solutions were used. These liquids permitted the use of wide variations in viscosity and some variations in density. The viscosity of the water used was approximately 1 cp. (depending upon temperature); the kerosene-carbon-tetrachloride mixtures, and lubricating oil permitted viscosity variation between 5 and 600 cps. The linseed oils varied between 800 to 20,000 cps, and the corn-syrup solutions were varied between 15 and 43,000 centipoises.

The density range of these liquids at their temperatures of operation was between 59.7 and approximately 90 lb./cu.ft.

Viscosities for water were taken from data in Chemical Engineers' Handbook (Perry) at the corresponding water temperatures. The viscosity of all other liquids was determined by means of Brookfield Model LVF and MVF, 4 speed, viscosimeters. For the higher viscosity liquids a calibration was made by means of the viscosimeter for a given solution or mixture at a series of temperatures. From these data calibration curves were made between viscosity and temperature for various mixtures. With high viscosity liquids where considerable power is consumed in mixing the energy is dissipated as heat, and the mixtures warm up rapidly; the viscosity changes appreciably. For all runs made at high viscosities the temperature was recorded at the moment torque and speed readings were made. Viscosities corresponding to the actual temperature of the liquid at the moment of the readings were used for calculations.

Densities were measured by means of hydrometers, and in the case of solutions and mixtures the variation of density with temperature was also calibrated, so that the proper density was used for calculations

corresponding to the density of the mixed liquid.

Liquid depth was varied between 0.55 to 1.2 tank diameters.

Various data pertaining to impeller size and shape, tank diameter, and extent of baffling as well as liquid viscosity and density are shown in the summary of experiments in Table 2.\*

Liquid temperatures were at room temperature or above, depending upon the heat generated by the mixing. In all cases temperatures were between 65° and 75°. Experiments outlined in Table 2 were performed over a period of several years.

**Experimental Procedure.** Runs were made in the various size tanks using the appropriate dynamometer setup. Liquid was placed in the tank, the impeller and shaft connected. Then the dynamometer was started, brought up to the desired speed and when conditions were steady, torque weight and dynamometer speed were recorded. The temperature of the mixed liquid was taken by means of a calibrated glass thermometer immersed below the surface of the liquid, approximately halfway between baffles and within 1/8 in. of the tank wall.

An important feature of this experimental work was to explore the power requirement for rotating mixing impellers in different viscosity and different density liquids. Few previous data in the literature cover experimental results for a given impeller over a wide range of viscosities in the same mixing tank. Moreover, care was taken to obtain overlapping Reynolds numbers: that is, Reynolds numbers of the same value were obtained by varying all three of the independent variables, namely  $D$ ,  $N$ , and  $\nu$  the kinematic viscosity.

### Experimental Results

Thousands of experimental determinations were made over wide ranges of the variables as summarized in Table 2. Too many data are available for detailed presentation, accordingly only a few typical data are tabulated in Tables 3 and 5.†

All results obtained are summarized in the form of plots of derived data appearing in the following figures and in tabular form in Table 6.† The characteristics of each impeller type will be taken up in detail, after which comparisons of the data for the various types and for the different size and boundary variables will be given.

**Propeller Characteristics.** Part of one set of runs, showing data typical of the action of a propeller, is given in Table 3. Data are for a 12-in. 3-blade marine-type propeller, 11.8-in. pitch, operated in a 54-in. diameter tank; liquid depth was 54 in., the impeller was 12 in. above the bottom of the tank.

The first section of data gives the results when no baffles were used in the tank, the next section when four 4.5-in. wide baffles (1/12 or 8.3% of tank diameter) were used, and the third section

\* See Note on p. 395.

† Tables 5 and 6 referred to in Part I will be published with Part II in the September issue.

TABLE 4.—VALUES FOR THE FROUDE NUMBER EXPONENT  $a$  AT REYNOLDS NUMBERS ABOVE 200

$a = -\frac{c - \log N_{Re}}{b}$				
a is zero for baffled conditions, or when no various are present, or at Reynolds numbers below 500.				
Propeller Diameter in.	Tank Diameter in.	F/D Ratio	a	b
4	5.5	2.1	2.6	18.8
20	54	2.7	2.3	19.0
12	54	2.0	2.1	19.0
4	10	2.8	1.7	19.0
12	54	4.5	0	19.0
Flat-Blade Turbine 6 Blades				
4	10	2.8	1.0	40.0
6	18	3.0	1.0	40.0

$a$  is zero for baffled conditions, or when no baffles are present, or at Reynolds numbers below 200.

when four 5.4-in. wide baffles (1/10 or 10% of tank diameter) were used. Altogether, Table 3 shows only 31 runs out of a total of 174 runs actually made for this propeller. To illustrate the further concentration of data, these 174 runs are presented in the three lines of Table 6 showing the results for the 12-in. propeller in the 54-in. tank.

Table 3 gives observed data and also the calculated values of power, Reynolds number, Froude number, power number, the exponent of the Froude number —  $a$ , and  $\phi$ . Data from the first part of Table 3, where no baffles were used, together with the other runs not tabulated, were used to plot the curves in Figure 12. This is a log-log plot of power number with Reynolds number and is a test of Equation (6). All data for various speeds of the propeller at Reynolds numbers below approximately 300 fall on a single line. It was observed visually that little vortexing of the liquid occurred at these low Reynolds numbers, but that vortex formation was increasingly evident as the speed of propeller rotation increased at Reynolds numbers above about 300. It is apparent from the plot that Equation (6) will correlate the data at low Reynolds numbers, hence, the Reynolds number alone is sufficient to describe dynamic similarity. The slope of the curve is —1 for Reynolds numbers below 10. A slope of —1 for such a plot is typical of "viscous flow" conditions in other fluid flow systems. Hence, in mixing operations the viscous flow range obtains at Reynolds numbers below 10. Substituting the value of —1 for  $m$  in Equations (6) or (7), the following equation results:

$$P = \frac{K}{g} \mu N^2 D^3 \quad (8)$$

This shows that for the viscous range, power is proportional to fluid viscosity, to the square of impeller speed, and to the cube of impeller diameter.

The value of  $K$  is characteristic of the impeller and its environment. Its value can be calculated for a given value of Reynolds number. Since data for the



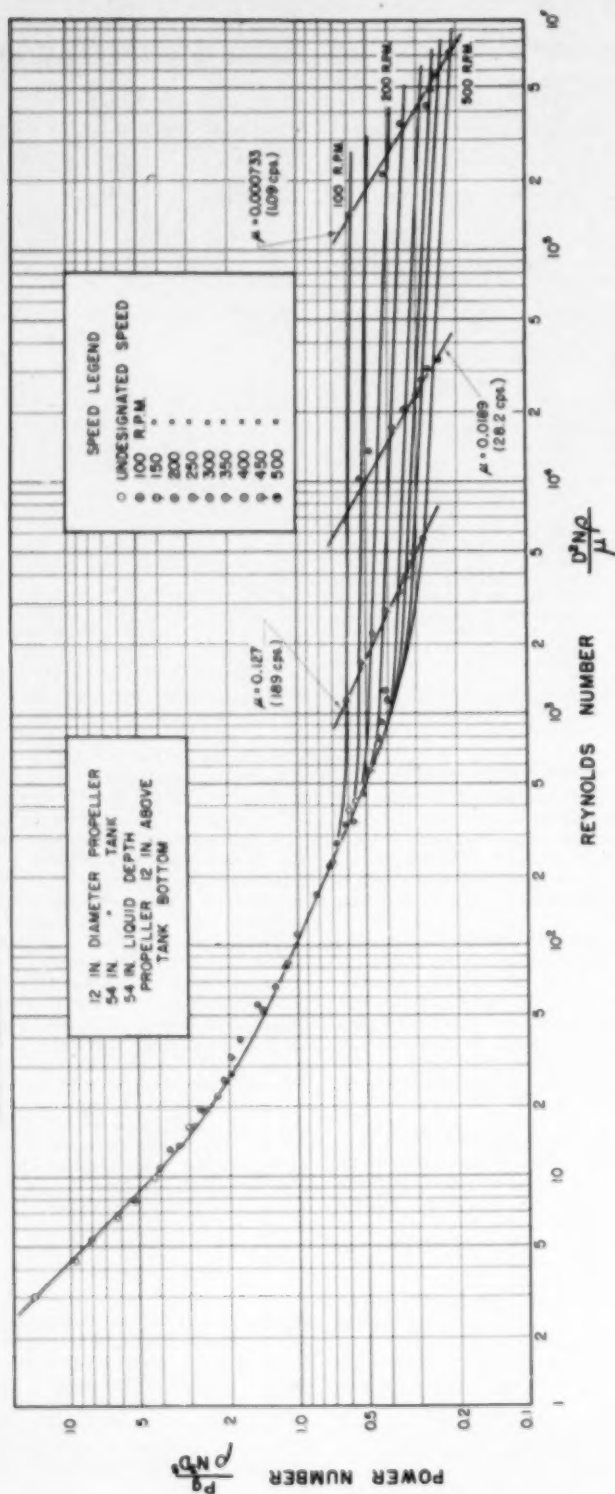


Fig. 12. Power, Viscosity, Speed, Reynolds Number Correlation for a Propeller Operating in a Mixing Tank without Baffles

viscous range were taken between Reynolds numbers of 1 to 10, it was arbitrarily decided to compare values of  $K$  in the viscous range at the Reynolds number of 5. From Equation (6), the value of  $K$  is equal to the power number at Reynolds number of 1; hence,  $K$  will equal  $5N_p$  at the reference Reynolds number of 5. Since the value of  $\phi$  is often used for the ordinate and applies as shown in Equations (5) and (6), the comparisons of all impellers are shown in Table 6 in terms of  $\phi$  at  $N_{Re}$  of 5, rather than as  $K$ . The value of  $K$  for Equation (6) is then equal to  $5\phi$  at  $N_{Re}$  of 5. Values of  $\phi$  at  $N_{Re}$  of 5 are given in Table 6 for all propellers operating without baffles. The value is practically constant at 8.3 over the range of sizes and conditions tested; hence,  $K = 415$  in Equation (8) for square pitch (pitch equal to diameter) marine-type three-blade propellers operating in unbaffled tanks in the ranges of conditions shown in Table 2.

Referring again to Figure 12, it is clear that at Reynolds numbers above about 300 the data do not lie on a single line. It is apparent that propeller speed and power cannot be correlated by means of Reynolds number alone. Curves have been drawn connecting points representing the same propeller speed at different Reynolds numbers. Also, the Reynolds numbers were varied by using different viscosities as well as by different speeds. The slanting lines representing three of the different viscosities used are marked on the plot; any one of them shows how power number varies with Reynolds number when speed is the only variable. At Reynolds numbers above 300 a vortex can be observed at all propeller speeds. This and the theory of dynamic similitude suggest that the Froude effect, or gravity, plays an important role. The magnitude of the Froude effect is seen, for example, in the value of the power number for a Reynolds number of 100,000. For a propeller speed of 100 rev./min.,  $N_p = 5.8$ , and for a speed of 500 rev./min.,  $N_p = 2.3$ , the Froude effect is less pronounced at lower Reynolds numbers and is of negligible influence at Reynolds numbers below 300. For the higher Reynolds numbers Equation 4 should apply, and the value of the exponent  $n$  should be evaluated.

If a plot is made of the power number with the Froude number for constant values of Reynolds number, it is evident that the Froude number is a function of the Reynolds number. By plotting the logarithm of the Reynolds number against the slope of the lines of the power number — Froude number plot a straight line results, from which the value of the Froude exponent  $n$  was found to be of the form:



values of  $N_{Re}$ , the curves can be constructed by drawing a line with a slope of  $-1$  through the  $N_{Re} = 5$  point, connecting this line with a smooth curve of the shape of Figure 13 through the point at  $N_{Re} = 200$ , and connecting with a line of small negative slope passing through the point at  $N_{Re} = 100,000$ . Note that between Reynolds numbers of 20 and 200 there is a small upward "hump" in the curves. Data are summarized in Table 6 in terms of values at the three characteristic values of  $N_{Re}$  for all propellers tested.

Curves of Figure 13 show the variations of power requirement with tank diameter-propeller diameter ( $T/D$ ) ratio, propeller pitch, and the use of baffles.

$T/D$  ratio affects power requirements only at high Reynolds numbers. It is sufficient that they be compared by noting the value of  $\phi$  at  $N_{Re} = 100,000$ . The curves and Table 6 show that  $\phi$ , and therefore the power, increases as  $T/D$  increases.

Curve 5 shows data for a propeller of twice the pitch used for Curve 3. Note that in the viscous range the data are identical, but the curve changes slope more rapidly and the values of  $\phi$  at  $N_{Re} = 200$  and  $= 100,000$  are much higher for the high pitch propeller. At  $N_{Re} = 100,000$  the higher pitch propeller has a power function of 0.52 compared with 0.29 for the lower pitch propeller.

It should also be noted that when propellers are rotated in tanks without baffles (or their equivalent) the flow pattern is as illustrated in Figure 3. This drawing shows a swirling flow with a deep vortex formed in the liquid. The depth of the vortex is a function of propeller speed, and as speed is increased the vortex will become deeper until it reaches the propeller. At this point gas touches the propeller and may be drawn into the liquid. The power necessary to drive the propeller, when gas and liquid are both in contact with it, is less than that required when in contact with liquid alone. This follows from Equation (5), which shows that power is a function of the Reynolds number and thus of the density of the liquid.

It was found experimentally that as propeller speed increased until the vortex reached the propeller, the power input increased. However, when the speed was increased above that at which the vortex was just short of entering the propeller, the power actually decreased. Hence, the maximum power that can be impressed on the fluid is reached when vortex depth is equal to propeller depth. Thus there is a limit to the power that can be imposed on a fluid flow system of this type where swirl predominates. This maximum power is a function of

the Froude number and can be related to it by vortex depth (14).

**Baffles with Propellers.** When baffles at the tank wall are used with propellers, the fluid regime is changed from that illustrated in Figure 3 to that shown in Figure 4. The baffles cause vertical currents of flow as well as lateral currents at many points in the liquid. Vortex and swirl can be eliminated by the use of such baffles, and under these conditions propellers are classified as axial flow impellers.

Data are given in Table 3 which are typical of propellers operating with baffles. Such data can be correlated by the use of Equations (6) and (7). Curve 6 of Figure 13 is from data where four flat baffles were placed symmetrically at the tank wall, each extending into the liquid on a tank diameter a distance of one-tenth tank diameter. Since with baffles of this type and size there are no rotary flow motions and thus no vortex, the liquid surface has no standing wave formation of sufficient size to require energy to overcome gravity. Thus, the Froude effect would not be expected to play a part in defining dynamic similarity. For Curve 6 the ordinate is the power number alone, and the data fall on a single line, showing that the Froude effect is absent under these baffled conditions and that Equations (6) and (7) will apply.

Curve 6 of Figure 13 is for a propeller whose pitch is twice its diameter, and Curve 2 of Figure 15 is for square-pitch propellers where pitch is equal to diameter. The curves are similar and are characteristic of all propellers tested under baffled conditions.

Equation (7) can be evaluated for use with propellers operating with baffles. For the viscous flow range, the value of  $m$  is  $-1$  and Equation (7) reduces to Equation (8). Moreover, the data almost coincide with those for non-baffled operation. The value of  $K$  can be computed from the value of  $\phi$  from Table 6 as outlined for the case where no baffles are present. In the transition range above  $N_{Re}$  of 10, the value of  $m$  varies from  $-1$  to 0, and the value of  $K$  is not constant. When the curves have a slope of zero at higher Reynolds numbers, the value of  $m$  in Equation (7) is zero and the equation reduces to

$$P = \frac{K}{g} \rho N^3 D^5 \quad (10)$$

The value of  $K$  is equal to  $N_P$  at  $N_{Re}$  of 100,000; values are listed in the last column of Table 6 for all conditions of operation.

Three reference values of Reynolds number can be used to characterize the curves of power number vs. Reynolds number, and the data for the different

conditions studied are tabulated in Table 6. As outlined above for propellers operating without baffles, the entire curve may be constructed by the data at these three points. At  $N_{Re}$  of 5 and the corresponding value of  $N_P$ , a line of slope of  $-1$  is drawn. This is connected with a curve passing through the  $N_P$  value at  $N_{Re}$  of 200, and joining a straight line of zero slope passing through the  $N_P$  value at  $N_{Re}$  of 100,000. The zero slope portion of the curve begins at  $N_{Re}$  of about 20,000 for square pitch propellers and from  $N_{Re}$  of about 10,000 for a pitch of two.

For viscous flow the values of  $N_P$  are nearly the same whether baffles are used or not and regardless of the propeller pitch. During the transition range differences in flow pattern and power response develop as a result of the presence of baffles. In turbulent flow conditions the power requirement is always higher (for the same propeller speed) when baffles are present, as is evident by comparing curves 5 and 6 of Figure 13, or by comparison of values of  $\phi$  at  $N_{Re}$  of 100,000 in Table 6.

Due to the absence of deep vortices when baffles are used, the speed of the propeller can be increased almost without limit without drawing gas into the propeller intake. Accordingly, there is no limit (with respect to liquid motion) to the power that can be imposed on the liquid flow by virtue of propeller speed. Equation (10) applies over a much larger range of propeller speed for baffled conditions than does Equation (4) for nonbaffled conditions.

**Off-Centered Propeller.** The off-centered position of a propeller whose shaft enters through the top surface of the liquid is shown in Figure 5. The position with respect to off-set from a diameter, angle with vertical, and to distance above bottom is critical and varies with liquid depth, tank diameter, and propeller size. This off-centered position is that wherein the highest power input can be obtained, and it is accompanied by a flow pattern without vortex in the liquid surface. Data are given in Table 6 which show that the off-centered propeller requires the same power as the same propeller operating in the vertical center position with four baffles each ten per cent of tank diameter. For this reason the off-centered position is considered equivalent to using baffles. Equation (10) applies at the off-centered position above Reynolds numbers of 20,000. If the propeller position is moved from the optimum as shown in Figure 5, a vortex will be formed and less power can be applied.

(Part II will appear in September issue.)

# INDUSTRIAL FRACTIONATING TOWER PACKING

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Performance characteristics are reported for a new type of industrial fractionating-tower packing having both higher capacity and improved "HETP" when compared with conventional bubble-cap towers. This packing is fabricated to form corrugated trays of multilayer, expanded metal lath. These trays are assembled to bring the ridges and valleys of adjacent trays into contact.

Experimental performance characteristics were obtained for vacuum conditions at 180 mm. Hg abs., atmospheric pressure and elevated pressures of 160 lb./sq.in.abs. in a small test tower. Commercial applications are reported for towers up to 4 ft. in diameter. Visual observations in a large air-water tower, which include motion picture studies, illustrate the operation of the packing and demonstrate positive distribution control.

In the atmospheric pressure range, if the packing is substituted in an existing tower for 36 bubble-cap trays on 1.5 ft. spacing, the resulting tower can give performance equivalent to more than 100 bubble-cap trays while operating at twice the maximum original loadings.

Savings reflecting up to a sixfold reduction in tower size may be realized in the principal cost items such as vessels, structural steel, foundations, insulation, transportation, erection charges, etc. Relatively large savings may also be realized when it is necessary to relieve capacity or fractionation limitations in existing towers.

THE conventional bubble-cap tower has withstood competition and major change during the last 25 years despite inherent and fundamental limitations upon performance. Capacity limitations result from double reversal of the vapor path through the bubble-cap tray and also from local vapor velocities

which are normally 7 to 10 times as high as through the tower section as a whole. A tower-packing study was undertaken to exploit potential packed tower advantages such as essentially linear vapor flow, avoidance of high local vapor velocities and vapor-liquid contacts at intervals of every few inches compared with the 18- to 30-in. intervals encountered with bubble-cap towers.

Recognizing the uncontrolled and usually poor liquid distribution of conventional packings, an effort was made to insure uniform liquid distribution, especially in large size towers. A form of packing was conceived which was composed of a number of layers of metal lath, compacted and bent into Vee shape. The trays thus formed were placed with the apexes of one layer touching the apexes of the layers above and below. In this manner it was anticipated that liquid would flow down two adjacent slopes, meet at the bottom, redi- vide on the next slope, etc. Preliminary tests with water, using air as the gaseous medium, showed that such an action did

in fact take place. An experimental program was therefore established for further developing this type of packing.

## Description of Tower Packing

Following the tests with the initial exploratory Vee-shaped packing, different forms were tried, such as sine-shaped, varying slope angle, varying amplitude, pore size, etc. A so-called No. 7 Series was among the better designs developed which has been subjected to rather extensive testing.

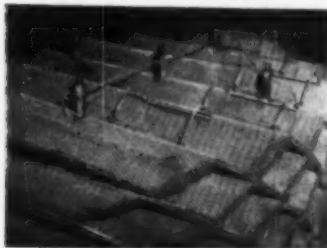


Fig. 1. Shop Assembly of Packing for a 4-ft. Diameter Heavy Virgin Gas Oil Stripper.

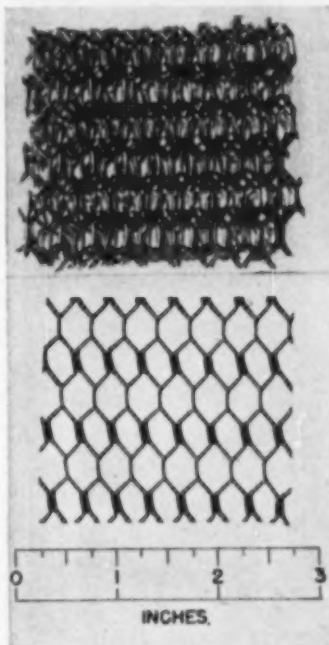


Fig. 2 (above). Section of a Packing Tray Employing Seven Layers of  $\frac{3}{8}$ -in. Diamond Metal Lath.

Fig. 3 (below). Single Layer of  $\frac{3}{8}$ -in. Diamond Metal Lath.



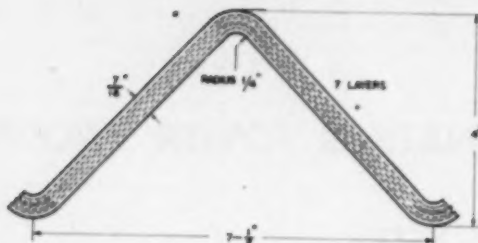


Fig. 4. No. 7 Series Packing Made of Seven Layers of  $\frac{3}{8}$ -in. Expanded Metal Lath.

The No. 7 Series packing employs corrugated trays which are superimposed to form a honeycomb-like assembly. Each tray is fabricated from seven layers of  $\frac{3}{8}$ -in. diamond mesh metal lath. Photographs of the packing are shown in Figures 1, 2, and 3. Figure 4 is a sketch providing physical details.

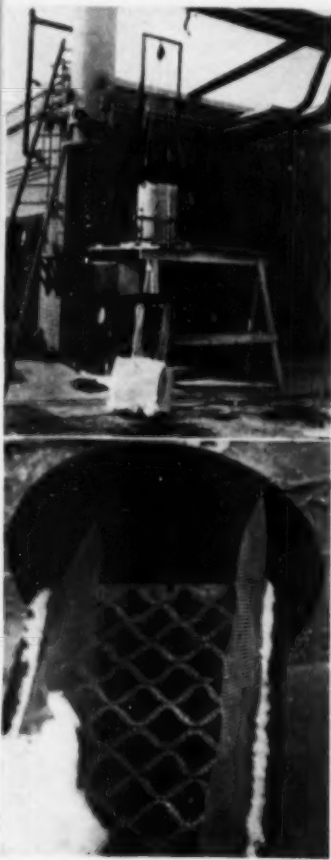


Fig. 5 (above). Experimental Tower Showing Top Section Swung Aside.

Fig. 6 (below). Cartridge Assembly.

The packing is the subject of a patent assigned to the Pan American Refining Corp. (16).

The most distinguishing characteristics of this packing are its open, unobstructed character and its large, open, cell-like sections extending across the full tower section. The many open sections function in equalizing pressures across the tower and establishing the controlled and uniform flow pattern considered necessary for the proper functioning of packing in large diameter towers.

Primary consideration is given to the No. 7 Series of the packing because it shows a balanced improvement in the principal phases of performance. Other forms of the packing have been tested and, as might be expected, have demonstrated superiority in specific phases of performance.

#### Description of Equipment and Procedure

Two types of equipment were used in this study; one type was constructed to permit visual observation on an air-water system, the other consists of steel equipment for detailed fractionation studies under various pressure conditions.

Air-water test equipment employing a rectangular tower with plate glass sides permitted detailed observation of the air and water distribution. These studies, by demonstrating positive control of distribution over a wide operating range, established that fractionation studies could be appropriately made in a small tower.

For the fractionation studies, an experimental tower was built employing  $2\frac{1}{4}$ - by 15-in. rectangular sections of packing in depths up to 4 ft. Figures 5 and 6 are photographs showing the experimental tower and the packed cartridge assembly which was installed in the tower for test purposes. Figure 7 is a cross-sectional sketch illustrating the general tower construction. The tower was constructed from ordinary 20-in. pipe for the tower shell and equipped with a built-in condenser and reboiler utilizing helically wound pipe. To facilitate change of packings the tower was flanged near the midpoint and the upper section was mounted on davits so that it could easily be swung aside. The cartridge of packing was supported and sealed by a ring fitting between the flanges of the tower.

The rectangular packing section used in the experimental tower was adopted so

that the same section of packing could be tested also in the air-water equipment. Some of the early experimental fractionation studies were made using a circular packing section in a 2 ft. diameter tower. The "H.E.T.P." data from this source agree closely with the data obtained on a rectangular section of the same packing when it was tested in the experimental tower. These observations confirm the expectation that the packing efficiency will be substantially independent of the size or shape of the packed section.

Since only process steam was available for reboil duty, it was necessary to select three different binary systems appropriate for vacuum, atmospheric and high pressure ranges, respectively. For the atmospheric pressure work, one degree Cooperative Fuel Research reference fuel benzene and toluene of comparable purity were employed and compositions were determined with a calibrated Cottrell boiling-point apparatus described by Griswold, Andres and Klein (7). In vacuum work ethylbenzene of 98.9% purity and the best available commercial isopropylbenzene were used. The latter was found to have traces of ethylbenzene and meta-xylene which did not impair its usefulness and, in addition, 1.4% paraffins. Composition of the ethylbenzene-isopropylbenzene system was determined by ebulliometric methods described by Swietoslawski (18). The high pressure data were obtained using Phillips' "pure" grade normal butane and normal pentane, and compositions were determined by either mass



Fig. 7. Experimental Tower Cross Section.

- (1) Condenser — Three helically wound coils connected in parallel.
- (2) Chimney for carrying vapors to top of tower.
- (3,4) Reflux trapped out at (3), returned by gravity to reflux distributor system at (4).
- (5) Entrainment separator.
- (6) Packing cartridge supported between flanges.
- (7) Jacketed drip collector insulated with loose granular Sil-O-Cel.
- (8) Radiation shield.
- (9) Reboiler—Divided into two circuits for individual or parallel use.



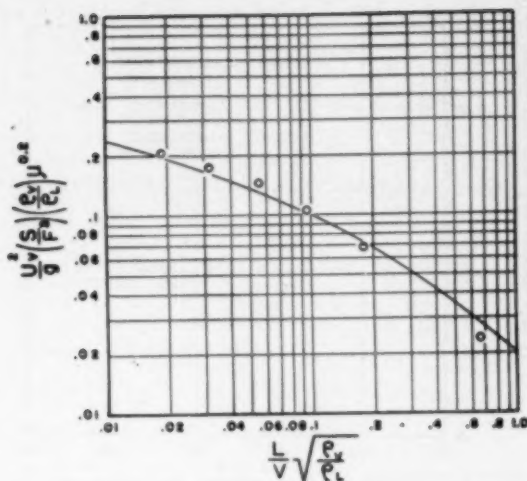


Fig. 8. Floodpoint Correlation of Air-Water Data Using  $S/F^3 = 30.7$ .

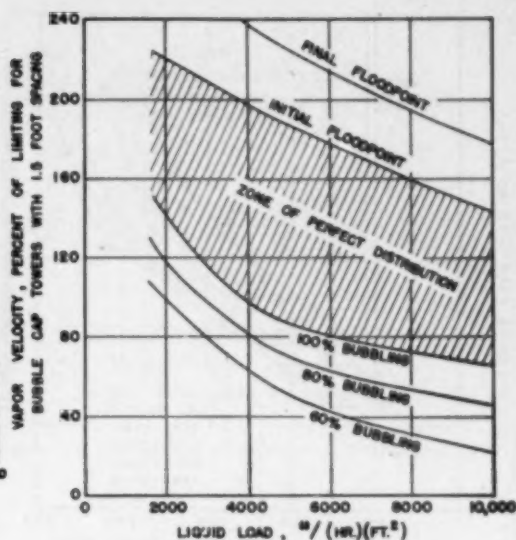


Fig. 9. Air-Water Performance.

spectrometer or spectrophotometric methods.

Blank runs were made with each of the three systems over the range of experimental operating conditions to determine the net amount of outside contacting due to the distributor, wall effect, etc. In subsequent experimental work with the packing deductions were made for this outside contacting as indicated in the tabulated summaries of experimental data.

**Capacity Studies.** Capacity studies have been made in the glass air-water tower as well as the experimental tower. Data obtained in these studies have been compared with regular packed tower correlations and bubble-cap tower performance from the standpoint of maximum capacity.

The basic floodpoint correlation normally used for sizing packed towers was developed by Sherwood, Shipley and Holloway (17) on the basis of dimensional analysis. The capacity constants for most packings are evaluated on the basis of measured surface area per unit tower volume and per cent free void space, and expressed in the form of  $S/F^3$ . Other factors such as vapor and liquid loadings and physical properties of the liquid and vapor are combined in the correlation and plotted in terms of the functions shown in Figure 8. Actually, the curve shown in Figure 8 is the slightly modified curve proposed by Lobo, Friend, Hashmall and Zenz (11). These authors extended the studies of the floodpoint correlation to include recent additional data from the literature and used modified values of  $S/F^3$  which

best fitted the experimental data. Their curve provides improved statistical correlation while retaining the same dimensionless grouping of variables. It is not practical to determine  $S$  and  $F$  factors for Scofield packing from the physical dimensions of the packing, and the packing characteristics are calculated from experimental floodpoint data using the curve of Figure 8.

Table 1 summarizes the air-water floodpoint data obtained with No. 7 Series packing. These data give an average  $S/F^3$  value of 30.7. Figure 8 is a plot of the experimental

points obtained by using the  $S/F^3$  value of 30.7. The close correspondence between these points and the curve shows that the flooding characteristics of Scofield packing agree closely with the Lobo correlation.

From this correlation it is evident that for given  $L/V$  ratios, densities and viscosities, the limiting vapor rate depends solely upon the  $S/F^3$  value. Interpreted in this way the  $S/F^3$  values are an indication of comparative capacity. When compared on this basis the six experimental values of  $S/F^3$  from the air-water tests show

TABLE 1.—SUMMARY OF INITIAL FLOODPOINT DATA AIR-WATER

Run	No. 7 Series Packing				
	Water Rate from Packing lb./hr. (sq. ft.)	Air Rate to Packing lb./hr. (sq. ft.)	Water Density lb./cu. ft.	Air Density lb./cu. ft.	Water Outlet Temperature °F.
7-RF	1,965	3,540	62.4	0.0732	62
7-AC	3,090	3,230	62.3	0.0730	65
7-L	4,570	2,790	62.2	0.0724	72
7-AM	7,200	2,560	62.2	0.0725	73
7-AT	11,100	2,100	62.1	0.0719	80
7-EL	28,400	1,320	62.1	0.0720	81

TABLE 2.—SUMMARY OF CAPACITY CONSTANTS DERIVED FROM EXPERIMENTAL DATA OF VARIOUS SOURCES

Source of Data	No. 7 Series Packing	
	$S/F^3$	Relative Capacity Based on $S/F^3$ Value
Average from air-water tests	30.7	100
Run No. 26 at atm. p-benzene-toluene system	30.2	100.8
Run No. 37 at 174 mm. Hg. abs. p., ethylbenzene-isopropylbenzene system	29.2	102.5
Run No. 117 at 150 lb./sq. in. abs., n-butane-n-pentane system	43.4	84.0

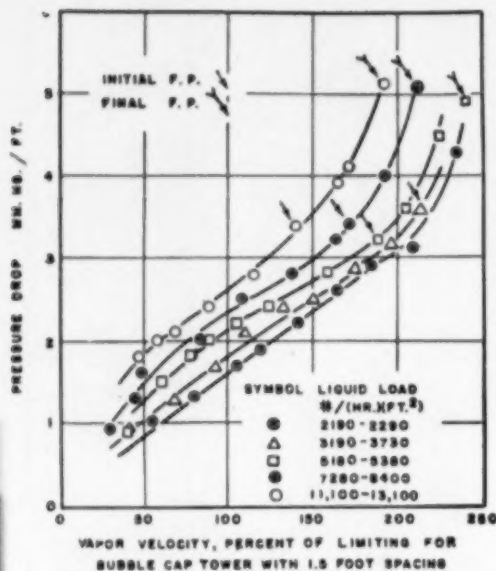


Fig. 10. Pressure Drop Data from Air-Water Studies.

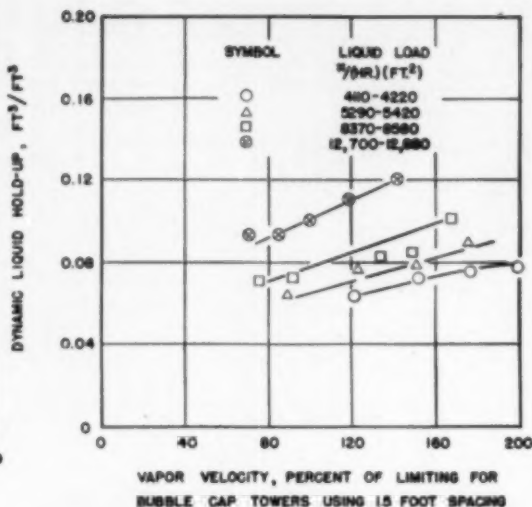


Fig. 11. Liquid Hold-up Data from Air-Water Studies.

an average deviation from their mean equivalent to 4.3% in terms of limiting vapor velocity.

Table 2 gives  $S/F^3$  values for this packing as determined from various sources of experimental data and includes corresponding relative capacities. It should be noted that the original correlation and essentially all literature floodpoint data involve vapor densities within the limits of 0.113 and 0.0051 lb./cu.ft. Comparable data for the air-water, vacuum, and atmospheric work are in good agreement. The high pressure work involves vapor densities about 20 times those used in establishing the original correlation

and a significant departure is noted for work in this range.

Some  $S/F^3$  values for representative common packings are taken from the article by Lobo, Friend, Hashmall and Zenz for their experimental wet packed and shaken case. Table 3 summarizes the  $S/F^3$  data and gives capacities relative to the No. 7 Series packing. These conventional-type packings are not used in large diameter fractionating towers, apparently because of lack of control over distribution. They are appropriate for small diameter towers where limited capacity is not objectionable. Because of the lack of literature

data on the conventional-type packed fractionating towers in sizes of 2 ft. and greater diameter, they cannot be considered from a competitive standpoint. Neglecting this disability for conventional-type packed towers, it is apparent from Table 3 that the No. 7 Series packing can be loaded to 250% of the loading permitted with 1-in. porcelain Raschig rings.

Recent studies and improvements in bubble-cap tray design made by Standard Oil Development Co. are reported by Rhys and Minich (15). This work has been credited with providing increased capacity for bubble-cap towers. These authors started with Equation (1) which is an established expression for the allowable superficial vapor velocities for bubble-cap towers and is described in the Chemical Engineers' Handbook (14).

$$U_m = k \sqrt{\frac{p_L - p_v}{p_v}} \text{ ft./sec.} \quad (1)$$

They proposed a substitution of the form  $k = K \sqrt{H}$  resulting in Equation (2) where  $H$  represents the distance between trays and  $K$  represents a fixed constant independent of tray spacing.

$$U_m = K \sqrt{\frac{p_L - p_v}{p_v}} H \text{ ft./sec.} \quad (2)$$

This equation was used to describe limiting commercial loadings on a crude

TABLE 3.—COMPARATIVE CAPACITY OF REPRESENTATIVE PACKINGS

Packing	$S/F^3$	Capacity Relative to No. 7 Series, %
No. 7 Series packing	20.7	100.0
1/2-in. Porcelain Raschig rings	544	19.5
1/2-in. Porcelain Raschig rings	600	22.6
1/2-in. Porcelain Raschig rings	249	35.0
1/2-in. Porcelain Raschig rings	199	39.2
1/2-in. Berl saddles (M. A. Knight)	589	32.4
1-in. Berl saddles (M. A. Knight)	250	35.0

TABLE 4.—COMPARATIVE CAPACITY OF BUBBLE-CAP TRAYS AND NO. 7 SERIES PACKING CRUDE FLASH TOWER SERVICE

Bubble-Cap Tray Spacing $H$ , ft.	Constant $k = 0.210 \sqrt{H}$	Capacity Relative to No. 7 Series Packing, %
1.5	0.256	55
2.0	0.303	65
2.5	0.332	71

flash tower utilizing the improved tray design. The value of  $K$  corresponding to their highest loadings was 0.210.

For purposes of comparison an "effective"  $k$  constant for Equation (1) may be calculated for No. 7 Series packing by employing experimental values of vapor velocities and densities and solving for  $k$ . Since the limiting loadings for the packing in experimental fractionation service were obtained at total reflux it might be expected that slightly higher vapor velocities could be obtained at the relatively low  $L/V$  ratios characteristic of crude flash tower operation. This somewhat higher vapor velocity may be calculated using the correlation shown in Figure 8. For example, in Run 27 the limiting vapor velocity for a benzene-toluene system at atmospheric pressure was found to be 6.88 ft./sec. at total reflux. By comparison, at the  $L/V$  value of 0.6 representative of crude flash tower service, the calculated limiting vapor velocity is 7.53 ft./sec. Substituting this value in Equation (1) and solving results in an effective  $k$  value of 0.466. The comparative limiting coefficient values for the bubble-cap tower, case of Rhys and Minich, takes the form  $k = 0.210 \sqrt{H}$ . The approximate difference in capacities is summarized in Table 4. The tabulated  $k$  constants and corresponding capacities can be associated only with optimum tray design and correspondingly low liquid loadings or  $L/V$  ratios.

For higher  $L/V$  ratios and equipment more nearly representative of general fractionation practice, the value of the constant is somewhat lower. For example, the 8-ft. diameter tower of the toluene unit at Texas City is limiting at loadings corresponding to a  $k$  value of 0.203. This tower was placed in service in 1943 and employs conventional cast iron caps and trays. The trays are of the double-flow type on 1.5-ft. spacing. Performance of this tower is considered to be fairly representative of bubble-cap towers and has been selected as a base case for comparison. The limiting vapor velocity of this tower is considered to be approximated by Equation (1) using the coefficient of 0.203. Some degree of orientation and comparison is provided by expressing the experimental packed tower vapor velocities in terms of per cent of the calculated limiting vapor velocities for the bubble-cap tower base case.

**Air-Water Observations.** Visual studies including motion pictures have been made using rectangular sections of packing behind plate glass and employing an air-water system. An index of the contacting efficiency within the packing was obtained by noting the action in the individual cells of the

honeycomb structure. In the course of these observations, pressure-drop measurements were made. Special interest was attached to the zone of operating conditions characterized by perfect distribution as evidenced by uniform and active bubbling along all slopes, usually 48 or more, and in all compartments. Figure 9 shows the perfect distribution zone as a function of varying air and water rates. In this operating range positive control of distribution has been demonstrated by introducing water at a single, high velocity point source at different locations, including along the furthestmost walls. Even this does not result in channeling since perfect distribution was reestablished within distances equivalent to about one tower diameter. Throughout this zone reproducibility of performance should be obtainable in any size tower. Parameters for "80% bubbling and 60% bubbling," representing bubbling on 80% and 60% of the slopes, respectively (two slopes per cell), are also shown in Figure 9.

All capacity ratings of the packing were determined on the basis of the "initial floodpoints." In the present work the initial floodpoint has been defined as the condition existing when the level of the bubbling zone has reached the middle of the diamond-shaped open sections or when this level has reached the ridges of the top trays.

At loadings above the initial floodpoint the distribution becomes unstable and channeling tendencies become progressively more noticeable. Consequently, loadings above the initial floodpoint line do not necessarily give reproducible or predictable performance. At sufficiently high loadings, the final floodpoint is reached, representing a condition in which there is considerable holdup on the top of the packing and

appreciable entrainment occurs out of the top of the tower. As a result, designs should be based on loadings falling within the perfect distribution zone. Figure 10 shows pressure-drop data for the air-water system plotted against vapor velocity, for parameters representing varying water rates. It will be noted that the initial floodpoint appears to occur at a pressure drop of about 3.5 mm. Hg.

**Liquid Holdup.** The holdup in fractionation equipment most frequently becomes a matter of primary concern in batch and superfractionation work. In these instances it is an important factor affecting, respectively, the sharpness of separations and the time to reach equilibrium. Experimental hold-up data were obtained in an air-water tower using quick-acting valves on both the water inlet and water outlet. This information is summarized graphically in Figure 11.

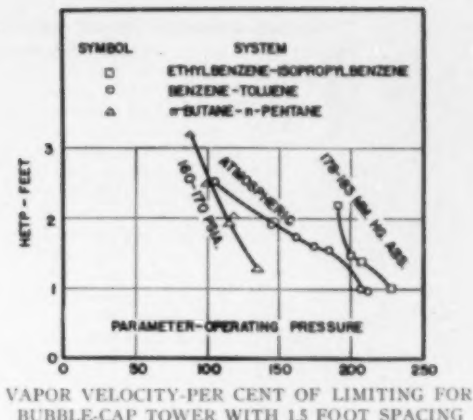


Fig. 12. Experimental Fractionating Performance at Total Reflux.

TABLE 5.—ATMOSPHERIC PRESSURE OPERATION NO. 7 SERIES PACKING

System: Benzene-Toluene		27	26	24	22	20	18
Run							
Vapor to packing							
Velocity, ft./sec.		6.88	6.94	6.00	5.77	5.32	4.54
Limit. vol. for bubble-cap towers, ft./sec.		5.27	5.29	5.24	5.21	5.21	5.23
Per cent of limiting vapor velocity		210	208	185	173	161	146
or, lb./cu.ft.		0.186	0.185	0.191	0.183	0.183	0.180
Liquid from packing							
lb./hr. (sq. ft.)		4640	4580	4140	3800	3500	3160
or, lb./cu.ft.		46.7	49.0	49.0	49.2	49.0	49.3
Tower operation conditions							
Top temperature, °F.		194.0	197.0	203.7	195.5	201.0	202.0
Bottom temperature, °F.		226.5	230.0	229.0	229.0	234.0	233.5
Pressure at top, lb./sq.in. gauge		0	0	1.35	0	0	0
Fractionation							
Reflux comp., mole % benzene		71.8	72.5	66.7	70.2	61.5	59.8
Bottom comp., mole % benzene		4.5	4.6	10.0	11.8	9.9	10.0
Theoretical trays							
Reboiler		1.00	1.00	1.00	1.00	1.00	1.00
Reflux distributor, wall effect, etc.		0.15	0.15	0.19	0.21	0.23	0.27
Packing		2.45	3.49	2.16	2.04	1.88	1.74
Observed overall		4.60	4.94	3.34	3.29	3.11	3.07
Depth of packing, ft.		5.23	5.23	5.23	5.23	5.23	5.23
"H.E.T.P." for packing, ft.		0.94	0.96	1.54	1.60	1.77	1.91
Pressure drop, in. Hg./ft. of packing		2.4	2.7	0.9	1.0	0.7	0.5

<sup>1</sup> Limiting vapor velocity for bubble-cap towers with 1.5 ft. tray spacing.

$$U_m = 0.203 \sqrt{\frac{g \Delta \rho}{\rho_f}} \text{ ft./sec.}$$

As indicated later, the equivalent tower using No. 7 Series packing would employ a packed section 5.5 ft. in diameter and 33.5 ft. in height. Under comparable conditions the holdup on the packing would be 74 cu. ft. or 3,530 lb. Consequently, the holdup for No. 7 Series packing is of an order of one-seventh as great as for bubble-cap trays.

**Atmospheric-Pressure Performance.** While visual observation on the air-water system is of interest in establishing the distribution through the packing, it is evident that any complete test program should also include "H.E.T.P." data. In addition, performance data un-

der vacuum as well as pressure conditions are necessary for a more complete appraisal of the packing. The experimental tower, illustrated in Figures 5, 6 and 7, permitted operation under various conditions and was therefore used for obtaining data of this character.

The choice of the benzene-toluene system for work at this pressure range was encouraged by the availability of plate efficiency data. Perry's "Chemical Engineers' Handbook" (14) reports 51.2 and 57% efficiencies for different experimental towers based on Carey's work. Griswold and Stewart (8) report 50 to 55% from their experimental work and 47 to 53 as calculated using the

Geddes (5) correlation. The Drickamer and Bradford (4) correlation gives 54% and the O'Connell (13) correlation gives 57%. For trays on 1.5-ft. spacing and tray efficiencies of 54% the "H.E.T.P." for the bubble-cap tower case is 2.8 ft.

Comparative performance of No. 7 Series packing is indicated in Table 5 and Figure 12. When the packed tower is operated at near optimum loadings it enjoys simultaneously a 2.9-fold advantage in "H.E.T.P." and a 2.1-fold advantage in capacity. Consequently, the packed tower at optimum conditions needs to be only one-sixth as large by volume in its fractionation section as the bubble-cap tower.

From the experimental curve it is evident that the packing performance is at its best near the initial floodpoint but it also provides a relatively wide range of operation. A large reduction in the charge rate to a tower may reduce the number of available theoretical trays. However, this effect is ordinarily counteracted by the resulting higher internal reflux ratio without any sacrifice of product quality. Of course, the maximum number of theoretical trays can always be realized by adjusting reboiler rates to provide the optimum tower loading.

**Vacuum Operation.** The low liquid loadings associated with vacuum operation would be expected to result in low liquid holdup, especially for conditions well below the initial floodpoint of the packing. In order to determine whether the No. 7 Series form of packing would operate satisfactorily with small amounts of liquid holdup, tests were undertaken using an ethylbenzene-isopro-

TABLE 6.—VACUUM OPERATION NO. 7 SERIES PACKING

System: Ethylbenzene-Isopropylbenzene		27	23	24	25
Run					
Vapor to packing					
Velocity, ft./sec.		13.65	12.54	11.92	10.73
Limit. vol. for bubble-cap towers, ft./sec.		8.95	8.45	8.93	8.96
Per cent of limiting vapor velocity		220	215	201	192
or, lb./cu.ft.		0.0565	0.0577	0.0569	0.0560
Liquid from packing					
lb./hr. (sq. ft.)		2780	2610	2450	2170
or, lb./cu.ft.		46.1	46.2	49.2	43.8
Tower operating conditions					
Top temperature, °F.		201.2	205.5	205.5	207.0
Bottom temperature, °F.		214.0	219.5	219.5	219.0
Operating pressure at bottom, mm.Hg. abs.		178	163	163	170
Fractionation					
Reflux comp., mole % ethylbenzene		49.9	46.2	50.6	41.4
Bottoms comp., mole % ethylbenzene		6.8	8.8	10.7	10.4
Theoretical trays					
Reboiler		1.00	1.00	1.00	1.00
Reflux distributor, wall effect, etc.		1.01	1.05	1.05	1.10
Packing		3.24	3.27	3.27	1.50
Observed overall		5.25	4.43	4.32	3.60
Depth of packing, ft.		3.33	3.33	3.33	3.33
"H.E.T.P." for packing, ft.		1.00	1.41	1.46	3.33
Pressure drop, mm.Hg./ft. of packing					
mm.Hg./thru. tray		4.3	3.0	3.3	1.50
		4.3	4.1	3.4	3.3

<sup>1</sup> Limiting vapor velocity for bubble-cap towers with 1.5 ft. tray spacing.

$$U_m = 0.203 \sqrt{\frac{g \Delta \rho}{\rho_f}} \text{ ft./sec.}$$

pylbenzene system. Results of these tests are summarized in Table 6 and Figure 12.

The experimental vacuum jet proved capable of maintaining operating pressures as low as about 180 mm. Hg. From the results obtained at this pressure it is evident that the No. 7 Series packing has only a narrow range of operation in which it demonstrates superior performance. This range falls just below the initial floodpoint and corresponds to increasing liquid holdup. Consequently, the more appropriate packing forms for vacuum operation provide longer inclines with correspondingly greater liquid loadings per incline.

A comparative study of commercial vacuum operation on an ethylbenzene-styrene system employing bubble-cap trays is helpful in evaluating the potential usefulness of packing forms. The first column of Table 7 is representative of commercial operation described in part by Mitchell (12). The "H.E.T.P." is in agreement with that reported by Geddes (6). Since there is considerable difference between top and bottom pressures in the commercial operation the pressure drops and vapor loading were associated with arithmetic mean pressure conditions to provide an approximate basis for comparison.

The last column of Table 7 gives experimental vacuum performance of No. 7 Series packing. Data were taken from the experimental Run No. 33 which is representative of the performance near the middle of the preferred operating range.

The middle column of Table 7 adjusts, in an approximate manner, the commercial performance to the experimental operating conditions. The method employed assumes the pressure drop to be largely due to the vapor loading and makes adjustments in terms of Equation (3), the basic orifice discharge formula normally employed in approximate liquid back-up calculations.

$$h_{fro} = C \left( \frac{p_v}{p_L} \right) U_r^2 \quad (3)$$

In summarizing the vacuum work it appears that at a pressure of 180 mm. of Hg. the packing has a narrow range showing superior operating performance. This is due primarily to low liquid holdup. The commercial and experimental "H.E.T.P." values are about the same at an operating pressure of 180 mm. Hg., but the packing is capable of loadings about three times as high as can be obtained with the bubble-cap towers for the same pressure drop of 4.1 mm. Hg./theoretical tray. The No. 7 Series packing performance improves as the operating pressure and therefore

liquid holdup is increased. This advantage increases up to sixfold with respect to tower size with atmospheric operation representing a limiting case. On the basis of air-water studies the range of perfect distribution increases rapidly when once the liquid holdup is sufficient to effect a liquid seal on the packing. This liquid seal is obtained with No. 7 Series packing at normal operating loadings when the operating pressure is somewhat higher than 180 mm. of Hg., or when the length of the inclines and therefore liquid downflow per incline is increased. Judging from air-water tests, larger cycle lengths cannot be tested effectively in the small section experimental tower since the serpentine path of the vapor tends to throw liquid against the tower walls, short circuiting the normal contacting zone. Consequently, experimental performance data have not been obtained on the more appropriate types of packings for vacuum service.

**High Pressure Operation.** The experimental high pressure performance obtained with the *n*-butane-*n*-pentane system can be compared with the fairly extensive data on commercial debutanizers and deisopentanizers reported by Drickamer and Bradford (4). Under the experimental conditions an over-all tray efficiency of 77% for bubble-cap towers would be predicted on the basis of their correlation. It should be observed that since the experimental operation was at total reflux it was necessary to substitute an average of the molal viscosities at the top and bottom of the tower for their feed stock molal average viscosity at the average tower temperature. For trays on 1.5-ft. spacing and

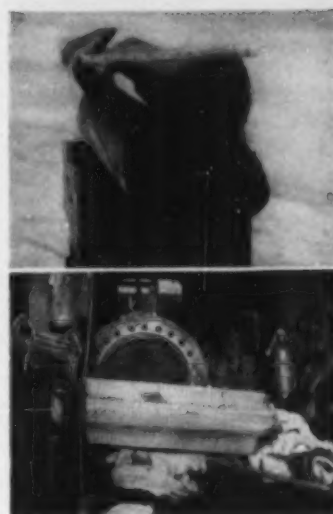


Fig. 13 (above). Rolled-up Tray.

Fig. 14 (below). Rolled Tray Inserted Through a Manway.

tray efficiencies of 77% the "H.E.T.P." for the bubble-cap tower case is 1.95 ft.

As shown in Table 8 and Figure 12, comparative performance of No. 7 Series packing at optimum conditions shows an "H.E.T.P." of only 1.33 ft. The corresponding loadings amount to 134.5% of the predicted limiting vapor velocity for bubble-cap towers with 1.5 ft. tray spacing. The resulting maximum advantage of the packing in tower size is therefore twofold in this high pressure range.

TABLE 7.—COMPARISON OF BUBBLE-CAP TRAYS AND NO. 7 SERIES PACKING IN VACUUM OPERATION

Data	Representative Commercial Bubble Cap	Adjusted Commercial Bubble Cap	Experimental Run No. 33 No. 7 Series Packing
Tower type	10 ft. 0 in.	10 ft. 0 in.	
Diameter, ft.	38	38	
No. of trays	125	125	
Tray spacing, ft.			
System	Ethylbenzene-Styrene	Ethylbenzene-Isopropylbenzene	Ethylbenzene-Isopropylbenzene
Pressures			
Top, mm. Hg. abs.	42	178	178
Bottom, mm. Hg. abs.	126	163	163
Densities			
$\rho_v$ , lb./cu.ft.	0.02663	0.0577 <sup>a</sup>	0.0577 <sup>a</sup>
$\rho_L$ , lb./cu.ft.	51.3 <sup>b</sup>	48.2 <sup>b</sup>	48.2 <sup>b</sup>
Loadings			
Vapor rate, lb./hr. (sq. ft.)	407	748	2610
Vapor velocity, ft./sec.	4.26 <sup>c</sup>	3.72 <sup>c</sup>	12.3 <sup>c</sup>
Limiting vapor velocity for bubble-cap towers, ft./sec.	8.10 <sup>a,b</sup>	5.35 <sup>a,b</sup>	5.35 <sup>a,b</sup>
Per cent of limiting vapor velocity	52.6	67.3	236.0
Pressure drop/theo. tray, mm. Hg.	2.5	4.1	4.1
"H.E.T.P." ft.	1.96	1.36	1.41

<sup>a</sup> Based on conditions corresponding to arithmetic mean operation pressure.

<sup>b</sup> Based on local conditions using temperatures and pressures reported under Run 33.

<sup>c</sup> Limiting vapor velocities for bubble-cap towers on 1.25-ft. tray spacing.

$$U_m = 0.185 \sqrt{\frac{p_L - p_v}{\rho_v}} \text{ ft./sec.}$$



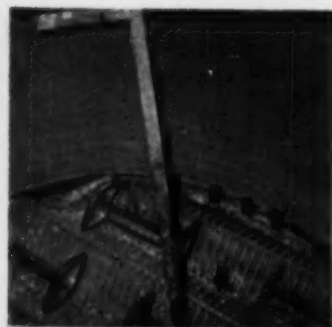


Fig. 15 (above). Assembly of Packing Within a Tower.



Fig. 16 (below). Installation of Fiber Asbestos at Tower Wall.

As shown in Figure 12, the "H.E.T.P." for the *n*-butane-*n*-pentane

system at high pressures tends to increase fairly rapidly as the tower loadings are reduced. This results in a narrower useful operating range than was observed for the experimental work at atmospheric pressure. The sharply reduced viscosity and surface tension characteristics of high pressure operation with the *n*-butane-*n*-pentane system are in the direction of encouraging liquid drip through the packing and therefore inadequate liquid holdup at rates much short of flooding. In this case a lower porosity packing than normally prepared from the  $\frac{3}{8}$ -in. diamond mesh metal lath should provide improved performance.

A different situation is presented in high pressure hydrocarbon absorber service. As a result of the relatively low temperatures employed it is common to obtain relatively high surface tension and high viscosities. This fact has been used to account for the comparatively low tray efficiencies usually observed for bubble-cap absorber towers. The increased surface tension and higher viscosity in absorber service favor relatively improved performance with ordinary No. 7 Series packing. This change in physical properties favors a relatively wide range of superior performance such as observed for the atmospheric pressure work.

**Packing Fabrication and Installation Methods.** The metal lath is normally supplied in 2 ft., 3 in. by 8 ft., 0 in. sheets. These are corrugated and assembled into layers by making overlaps of 1 in. to  $2\frac{1}{2}$  in. The seven-layer rough trays are "tacked" together and trimmed with a metal cutting saw to a desired radius. It has been found that the cut-



Fig. 17. Feed Distributor for a 4-ft. Diameter Stripper.

ting time per tray or section for a 4-ft. diameter tray is less than 30 min.

When packing may be installed to the full diameter of the tower the procedure is simplified. Figure 13 illustrates the facility with which a 4-ft. diameter tray may be formed into a small diameter roll. Fortunately, this does not cause stresses beyond the elastic limit of the metal lath since when the ties are released the tray springs back to its original shape without distortion. Figure 14 shows a tray in the process of being passed through a manhole. The packing is supported on a grid which also serves to anchor several sectional tie bolts extending through the full packed section. Figure 15 is a view inside a tower showing packing in the process of installation. The rectangular reinforcement cages are used only in large diameter towers to help maintain appropriate registry of the ridges and valleys of the packing. These cages also distribute the load of workmen within the tower without injury to the packing. The heavy lath or screen material shown in the background is spliced as indicated using clips resembling double-ended clothespins. Between this surrounding layer and the tower wall fiber asbestos is tamped into place to provide a wall seal as shown in Figure 16. The type distributor shown in Figure 17 is relatively streamlined and avoids the creation of a local capacity bottleneck. The rows of holes are spaced on the basis of calculated liquid trajectory and provide a fairly uniform liquid loading on the top tray.

In relatively smaller towers packing may be installed as prefabricated cartridges using a ring seal at the top of each cartridge. In some cases regular pipe sections 6 ft. long may be used for

TABLE 8.—HIGH PRESSURE OPERATION NO. 7 SERIES PACKING

Run	System: <i>n</i> -Butane- <i>n</i> -Pentane				
	117	119	119	120	121
Vapor to packing					
Velocity, ft./sec.	1.055	0.905	0.934	0.788	0.678
Limit velocity for bubble cap towers, ft./sec. <sup>1</sup>	0.786	0.765	0.800	0.700	0.700
Per cent of limiting vapor velocity	134.5	118.0	117.0	99.8	86.0
$\rho v$ , lb./sq.ft.	1.91	2.00	1.86	1.90	1.80
Liquid from packing					
Lb./hr. (sq ft.)	7270	6520	6130	5390	4640
$\rho v$ , lb./sq.ft.	30.5	30.5	30.9	30.7	30.7
Tower operating conditions					
Top temperature, °F.	202	205	202	207	213.5
Bottom temperature, °F.	257	253	249	251	251
Pressure at top, lb./sq.in. abs.	150	155	145.5	151	151
Fractionation					
Reflux comp., mol. % <i>n</i> -butane	83.7	80.2	82.1	76.8	72.9
Bottom comp., mol. % <i>n</i> -butane	19.8	19.5	19.8	20.6	20.6
Theoretical trays					
Reboiler	1.00	1.00	1.00	1.00	1.00
Reflux distributor, wall effect, etc.	1.06	1.08	1.08	1.09	1.10
Packing	2.76	1.79	1.50	1.42	1.14
Observed overall	4.82	3.87	3.57	3.51	3.24
Depth of packing, ft.	3.67	3.67	3.67	3.67	3.67
"H.E.T.P." for packing, ft.	1.33	2.05	1.94	2.58	3.20
Pressure drop, mm.Hg./ft. of packing	2.1	1.1	0.8	0.6	0.4

<sup>1</sup> Limiting vapor velocity for bubble cap towers with 1.5 ft. tray spacing.

$$V = 0.203 \sqrt{\frac{g \Delta \rho}{\rho}} \text{ ft./sec.}$$

the cartridge wall. If these sections are welded together, no other tower wall is necessary.

The installation of packing is a critical process involving exacting work and requiring know-how. The quality of this work is reflected in the resulting performance of the packing. In comparison with bubble-cap trays the installation of packing calls for more careful work and control but requires about the same number of man-hours.

In the installation of No. 7 Series packing the prospect of possible fouling deserves consideration. It has been found that fine suspended matter lacking in adhesive properties can pass through the packing under conditions that would promptly clog bubble-cap trays. If it were desired to clean a packed tower the packing would be removed, sand-blasted and reinstalled. The down time for this operation probably would not exceed the time required to clean bubble-cap trays having spacings of less than 2 ft. While each case should be considered separately, it might be observed that no filtering or other special provisions have been recommended for the commercial installations made to date.

### Commercial Applications

The initial commercial application was in a pipe still virgin gas oil stripper employing only an 18-in. diameter packed section and processing up to 1,500 bbl./day of gas oil. An unexpected aspect of this installation developed when the pipe still was employed alternately for topping and asphalt production. In the asphalt operation the stripper charge was dirty, consistently giving a product having an off-scale ASTM 8+ color. At a recent inspection after 18 months of service, no fouling was found.

The second installation of packing was employed to replace the 4-ft. diameter bubble-cap trays on 2.5-ft. spacing in a heavy virgin gas oil stripper at a thermal cracking unit. In recent years it has been necessary to operate this stripper to produce consistently 13,000 bbl./day of gas oil as charge stock for the catalytic-cracking unit. Because of fractionation limitations of the original bubble-cap trays this stream had been deficient in quality. For example, during the last four months of 1947 this gas oil showed an average flashpoint of 166° F. and an average 400° F. end-point naphtha content of 8.3%. After installation of packing the tower capacity was increased so that while producing 13,000 bbl./day of gas oil the limiting steam rate was raised from its former value of 1,000 lb./hr. to a new value of 1,750 lb./hr. As a result of

improved stripping the 400° F. end-point naphtha content has been maintained at zero and the flashpoint has been raised to 196° F., resulting in an improved charge stock to the catalytic-cracking unit.

### Superfractionation

It is in only recent years that extensive commercial fractionation work has been undertaken involving separations too difficult to be effected in single bubble-cap towers. The continuing extension of fractionation work into this field encourages comparison of bubble-cap trays and this packing, particularly with respect to both practical and economic limits.

In current practice difficult separations are effected by employing two bubble-cap towers joined in series and employing a single reboiler and overhead system. Tower systems of this kind are used in the fractionation of a butane-butylene-butadiene mixture as described by Happel, Cornell, Eastman, Fowle, Porter and Schutte (9). In this work two towers, each 50-tray towers with 2 or 2.5 ft. tray spacing, are connected to provide the equivalent of a 100-tray tower. Similar tower arrangements described by Birch, Docksey and Dove (2) were employed in the Near East during World War II to provide isohexane and isoheptane fractions from straight-run gasoline. One of the earliest and most extreme examples of superfractionation is described by Arnold (1) and involved four 50-tray towers in series to provide the equivalent of a single 200-tray bubble-cap tower.

Generally speaking, the economic status of superfractionation appears to be poorly understood. The operating costs with respect to utilities are far too low, especially in the Gulf Coast area, to exert a controlling influence on the practical limits of fractionation. Current practice has been limited primarily to two tower systems employing a total of usually 100 bubble-cap trays. If, for example, the system should have properties resembling the benzene-toluene system, the towers would provide the equivalent of about 54 theoretical trays. Harbert (10) has found that the most economical fractionator is obtained when the number of theoretical trays employed is about twice the minimum required at total reflux. On this basis the representative two-tower system is appropriate for separations requiring about 27 theoretical trays at total reflux. Separations of this degree of difficulty require a ratio of boilup to fresh feed of an order of 7 to 1. Since this implies a reboiler duty of only about 1200 B.t.u. for each pound of fresh feed, it will be

evident that the cost of utilities can be nearly insignificant. This is particularly true along the Texas-Louisiana Gulf Coast where the cost of industrial fuel gas is frequently as low as 7 cents per million B.t.u.'s of heating value.

The complexity and high equipment costs for the bubble-cap tower superfractionator provides an interesting contrast with an equivalent packed superfractionator. If three bubble-cap towers of 8 ft. diameter, and each having 65 trays on 1.5 spacing, are employed in series operation, they could be replaced with a single, packed tower 6 ft. in diameter of the height of one of the bubble-cap towers. Besides resulting in improved operability this would eliminate outside costs such as pumps, provision for intermediate liquid retention time, interconnecting piping, instrumentation, etc.

The role of superfractionation is destined to increase in importance as a means of providing pure hydrocarbons from petroleum, separating isomers and isotopes and increasing the purity levels of products under the stimulus of competitive enterprise. With the availability of new tools superfractionation processes warrant further consideration, particularly since the surface in this field has only been scratched.

**Cost Comparison.** In the construction of new fractionation equipment the alignment of materials costs shifted near 1945 and since then it has been less costly to use 410 stainless steel bubble-cap trays than cast iron. This shift is reported by Bliss (3). In consistency with current practice, comparative costs are referred to 410 stainless construction using the costs quoted by Bliss as representative of the spring of 1947. The comparison is facilitated by considering a per-cubic-foot cost of the 8-ft. diameter toluene unit tower with 1.5-ft. spacing as representative of conventional equipment and comparing this with the cost of equivalent packing. A single 8-ft. tray costs \$750 plus \$275 for tray supports, installation costs included. This is equivalent to \$13.60/cu.ft. of fractionation section.

For comparison, the No. 7 Series packing, after allowing 20% waste, requires 42 sq. ft. or 15 lb. of 18-8 stainless steel metal lath at \$1.00/lb. After taking into consideration the up to six-fold volumetric efficiency advantage of the packing it will be evident that packing equivalent to one cubic foot of space in the conventional bubble-cap tower costs only \$2.50 for the metal lath. The other costs, such as fabrication and installation, leave a substantial margin of advantage for the packing.

The comparison thus far has been concerned with the internal parts of the

towers. It will be evident that savings consistent with up to a sixfold reduction in tower size can be realized for the remaining items which constitute the principal elements of cost. These latter items include vessel, insulation, foundations, structural steel, freight, erection, etc.

For difficult separations requiring two or more bubble-cap towers in series the same results can be had with a single packed tower with resultant savings in pumps, intermediate liquid holding facilities, instrumentation, etc.

When it comes to relieving capacity or fractionation bottlenecks in existing equipment the conventional bubble-cap trays frequently offer no solution short of building an entirely new tower. Packing may be substituted for bubble-cap trays in existing towers to frequently double capacity or increase the number of theoretical trays by threefold.

### Conclusions

The No. 7 Series packing is appropriate for commercial fractionators in sizes ranging from near 2 ft. to unlimited diameters. Its performance and cost advantages over bubble-cap towers are greatest in the operating range from near atmospheric to about 75 lb./sq. in. abs. in fractionation service.

Relative margins of advantage diminish in fractionation service as operating pressures are carried above this range or as operations are extended into the high vacuum range. Modifications of the No. 7 Series packing possess somewhat greater advantages under operating conditions falling outside this optimum range.

Careful consideration of the use of No. 7 Series packing is particularly recommended for superfractionation, batch fractionation, absorbers, difficult separations and the removal of limitations in existing equipment.

### Acknowledgment

The work covered in this paper was carried out as a research project of the Pan American Refining Corp., Texas City, Tex., and permission to publish the results of this project is acknowledged by the author.

### Notation

$F$  = fractional voids in packing, no units

$g$  = acceleration of gravity, ft./sec.<sup>2</sup>

$h_{pe}$  = height of liquid back-up due to pressure drop through risers and caps, in.

$H$  = tray spacing, ft.

$k$  = a constant depending on tray spacing, etc., ft./sec.

$K$  = a constant independent of tray spacing, ft./sec.

$L$  = liquid rate, lb./hr. (sq. ft.)

$S$  = surface area of packing/unit volume, sq. ft./cu. ft.

$U_m$  = limiting superficial vapor velocity for bubble-cap towers, ft./sec.

$U_r$  = vapor velocity through risers, ft./sec.

$U_v$  = superficial vapor velocity through a packed tower, ft./sec.

$V$  = vapor rate, lb./hr. (sq. ft.)

$\rho_v$  = vapor density, lb./cu. ft.

$\rho_L$  = liquid density, lb./cu. ft.

$\mu$  = liquid viscosity in centipoises

$c$  = a constant

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### Discussion

**Anonymous:** Is this type of packing adaptable to vacuum distillation?

**R. C. Scofield:** This paper is concerned with only the No. 7 Series form of the packing and this was developed primarily for general applications at near atmospheric pressure. Vacuum and also high pressure data have been included to show that the packing can be used in these ranges. Since the No. 7 Series form of packing shows a comparatively narrow range of satisfactory operation in the vacuum and high pressure regions it would ordinarily be preferable to use other variations of the packing. Other forms which have been tested provide different cycle lengths, slopes and porosities appropriate for vacuum applications or for high pressure applications.

**Anonymous:** Has any work been done on this type of packing with lower cross-sectional areas and for smaller tower diameters, say, between 12 in. and 2 ft.?

**R. C. Scofield:** An installation of this kind has been in service for more than two years and uses a 17-in. diameter packed section. The packing was installed in a cartridge form but a modified type of the packing was used.

**Anonymous:** How does the capacity of the column change with the size of the openings in the metal lath? Also, do you use a definite arrangement of the several layers of metal lath making up one tray or a section of packing?

**R. C. Scofield:** Pore size is just one of the many variables explored in the development program. For the present it would seem desirable to stick rather close to the one form of packing known as No. 7 Series. In this packing a standard  $\frac{3}{8}$ -in. metal lath is used and it has the same form as that used by the building trades. It is not necessary to bring the diamond mesh openings into registry or into fixed relative positions.

**Anonymous:** In the installations, is it necessary to arrange the sheets in any special order and is it necessary to maintain a definite spacing?

**R. C. Scofield:** Entire trays of packing are assembled prior to installation step and these are ordinarily rolled up for insertion through manways. In installation, the trays are superimposed so that the valleys of one tray rest on the ridges of the tray underneath. This method controls the tray spacing.

(Presented at Forty-second Annual Meeting, Pittsburgh, Pa.)

# PRESSURE DROP THROUGH POROUS MEDIA

## PART IV—NEW DATA<sup>†</sup> AND REVISED CORRELATION

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New data on flow through porous media are presented for packed beds covering a range from completely laminar to highly turbulent flow, and a porosity range from 40 to 94 per cent. Observed pressure drops are compared with those predicted by various correlations. The method of correlation presented in Part I of this series has been revised.

SINCE publication of Part I (2) of this series, entitled "Single Homogeneous Fluids," new data have been obtained which clarify some issues arising in the discussion of this paper. Fluid-flow data covering a wide range of Reynolds numbers, from completely laminar to highly turbulent, and covering a porosity range from 40 to 94 per cent indicate that the original correlation was as accurate as any of the relationships commonly used in this field. These new data, however, point to a revision and permit the development of a modification which is more accurate and direct in its application to the solution of problems involving flow through porous media.

### Apparatus

Figure 1 is a photograph of the laboratory apparatus used in obtaining data on the smaller-sized particles. Additional data for the larger-sized particles were obtained in a similar but larger tower. Figure 2 represents a general schematic piping diagram of this equipment.

As a check on existing data, a preliminary run was made using the smaller tower packed with closely sized glass spheres. Subsequent flow data were then obtained for a packing consisting of stamped nickel saddles having a porosity of about 93 per cent. A similar type of packing having a slightly higher

porosity and artificially roughened by surface protrusions was employed to study the effect of roughness. Finally, large-sized packings consisting of commercial clay Raschig rings and Berl saddles were investigated in the larger tower. Figures 3-7 are photographs of these particles and the properties of these packing materials are listed in Table I.

*Test Procedure.* At the outset of this investigation it was known that porosity

is a variable of prime importance in the flow of fluids through porous media. In order to insure a constant porosity during the test run, an initial flow was maintained at the maximum operating pressure drop to compact the bed until no further change in porosity was detected. The bed was not disturbed until all flow tests were completed. The Reynolds number of the fluid was varied both by varying the flow rate and changing the particular fluid in the system. The fluids employed in these tests included hot and cold water, sugar solutions of various viscosities, and SAE No. 60 oil. Data thus obtained are plotted as a modified friction factor versus a modified Reynolds number on Figures 8 and 9.

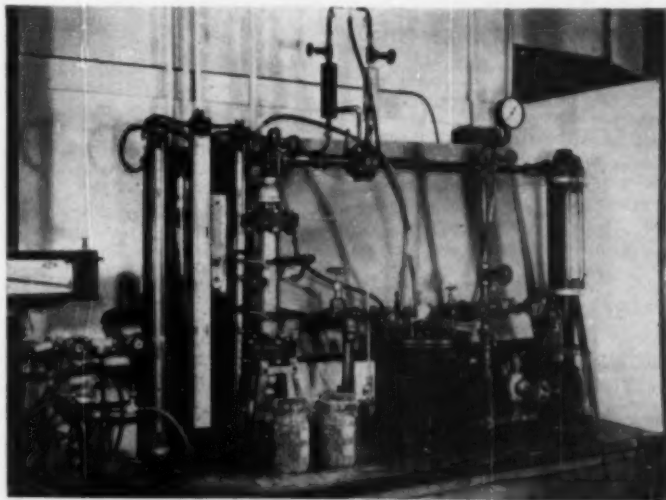


Fig. 1. Photograph of Laboratory Apparatus.

<sup>†</sup> Complete data of Table 2 are on file (Document 2827) with the American Documentation Institute, 1719 N Street, Northwest, Washington 6, D. C. Obtainable by remitting 50 cents for microfilm and 80 cents for photoprint.



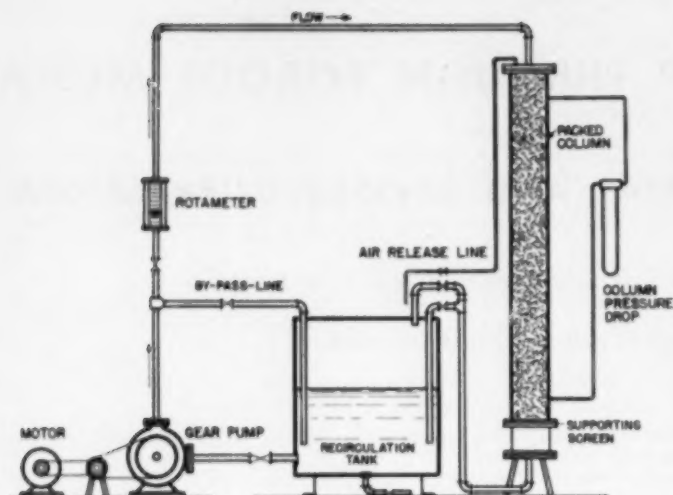


Fig. 2. Schematic Diagram of Experimental Equipment

**Comparison of Data with Correlations.** Figures 10-12 for laminar flow, and Figures 13-15 for turbulent flow, compare the experimental pressure drops with the pressure drops predicted by the correlations of various investigators (2, 4-6, 9). Figures 16 and 17 show the per cent deviation of these predicted pressure drops from the experimental data given in Table 2 for the laminar region,  $Re = 0.1$ , and the turbulent region,  $Re = 1000$ , respectively. It may be observed that all methods agree fairly well with the data for the closely sized glass spheres of 41.2% porosity. However, at higher porosities, the deviations of the predicted pressure drops from the observed values tend to become greater for all correlations.

**Revised Correlation.** In order to correlate or reduce all fluid-flow data to a single plot or expression, some reference must be selected. A few investigators arbitrarily chose the data for spherical particles of 40% porosity as this reference. There is nothing absolute about this particular reference, and, in fact,

beds of particles of any other shape and porosity might have been selected. Different beds of identical particles having the same porosity do not necessarily yield exactly the same pressure drop for random packing. It must be realized that each randomly packed bed is individual and unique, and is incapable of exact duplication as a result of slight but significant differences in geometrical arrangement. Martin (7) has reported data for stacked beds of spheres which reveal differences in pressure drops of as much as 50 per cent for beds of identical porosity. This observation would appear to limit the accuracy with which any correlation could predict pressure drops for flow through randomly packed media. For this reason, selection of a particular porous medium as a reference does not appear satisfactory. The authors believe the Fanning friction factor—Reynolds number relationship for flow through conduits as employed in Part I to be a more absolute and familiar reference.

The significance of using the pipe-plot as a reference for correlation becomes apparent when fluid flow through porous

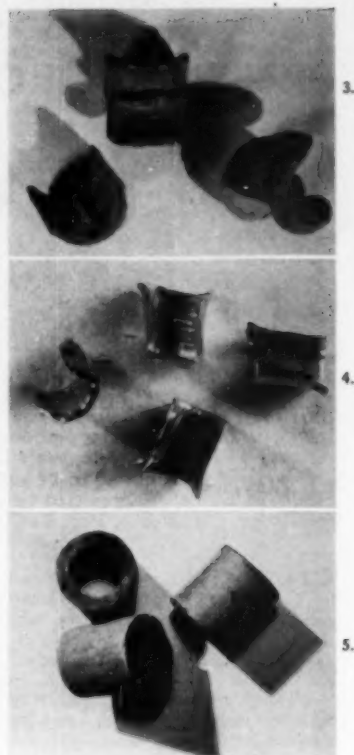


Fig. 3. Photograph of Clay Berl Saddles.  
Fig. 4. Photograph of Smooth Nickel Saddles.  
Fig. 5. Photograph of Clay Raschig Rings.

media as described by the "modified" Reynolds number and friction factor is compared with flow through conduits. This particular correlation takes the form of a correction of the variables involved in these "modified" terms to their basic meaning as applied to flow in true conduits. The fundamental differences in the Fanning and modified terms arise in the diameter, velocity, and length of path variables. In flow through porous beds, the effective pore diameter is usually less than the particle diameter. This correction enters both the Reynolds number and friction factor and is shown in vector form as  $D$  in Figure 18. The linear velocity of the fluid through the pores is considerably greater than the superficial velocity. A correction for velocity is represented as a vector  $v$  with a slope of  $-2$ . Finally, the length of path of the fluid through the bed is greater than the actual length of the bed. This variable enters the friction factor only and is also represented in Figure 18 as  $L$ . Since the velocity correction is by far the greatest in magni-

TABLE 1.—PROPERTIES OF POROUS MEDIA PARTICLES

Packing Material	Particle Diameter $D_p$ , ft.	Bed Porosity $\epsilon_{acc}$	Particle Sphericity $\psi$	Particle Area sq. ft.	Particle Volume cu. ft.
Berl saddles	0.0833	0.725	0.370	0.0343	$1.35 \times 10^{-4}$
Raschig rings	0.0833	0.707	0.391	0.0390	$1.93 \times 10^{-4}$
Glass spheres	0.0174	0.413	1.000	$9.45 \times 10^{-4}$	$8.21 \times 10^{-5}$
"Smooth" nickel saddles	0.0110	0.931	0.140	$6.35 \times 10^{-4}$	$7.84 \times 10^{-5}$
"Rough" nickel saddles	0.0108	0.935	0.140	$6.35 \times 10^{-4}$	$7.84 \times 10^{-5}$



tude, the resultant correction vector has a slope greater than, but approaching -2.

The Brownell-Katz correlation (2) presented the horizontal and vertical components of this resultant correction in terms of the bed porosity raised to an exponent, or  $1/X^m$  and  $X^n$ , respectively. While this method was useful for correlating limited data, it was found that these exponents rise rapidly as the porosity approaches unity, making some calculations awkward and inconvenient. The authors have followed a simpler approach and have correlated the numerical value of the porosity functions directly, without solving for the exponents. This correlation takes the form of plots of these porosity functions against porosity with parameters of particle sphericity.

Values of these porosity functions

were obtained by superimposing the experimental data on the pipe plot. The curvature of the plotted data in the turbulent region approached that of the line for smooth pipe better than it did the lines for pipes of higher roughness. Contrary to expectation, the curves for the "smooth" and "rough" nickel packing were found to be practically identical in shape. The rough packing showed a lower pressure drop which can be attributed to the difference in porosity. This observation appears to substantiate the opinion of many investigators that particle roughness is a minor variable in the flow of fluids through random-packed particles. Whatever the effect of roughness may be, probably it will have to be determined in a bed of oriented particles where this effect can be isolated.

The new data make possible plots

(Fig. 19 and 20) of these porosity functions against porosity with parameters of sphericity. Use of these plots does not assume any particular relationship between sphericity and porosity, nor any interdependence of porosity, sphericity and the Reynolds number—friction factor plot for pipe. The only assumption made is that porosity and sphericity are each variables which influence flow through porous media, and that these variables together with those in the modified Reynolds number may be used to correlate the fluid-flow data on the Reynolds number—friction factor plot for flow through smooth conduits. No allowance is made for particle orientation. However, owing to the nature of this correlation, it may be used to predict approximate results for stacked beds. The experimental data indicate that roughness is not a major variable and is

TABLE 2.—PORTION OF ORIGINAL DATA\*

Packing	Run No.	Temp. °F.	Density lb./cu.ft.	Viscosity cp.	Flow Rate G (sec.)	Pressure Drop $\Delta P/L$ lb./sq.ft. (ft.)	Fract	Re <sub>max</sub>
1. Glass spheres	151	90.5	81.4	0.9	0.0850	4.10	52,300	0.0344
	152	90.5	81.4	0.107	0.107	4.925	29,700	0.0433
	150	90.7	81.4	0.201	0.201	0.32	20,400	0.0834
	160	90.7	81.4	0.316	0.316	15.50	14,100	0.1287
	163	90.7	81.4	0.402	0.402	20.1	11,210	0.1659
	165	90.9	81.4	0.527	0.527	25.9	8,450	0.216
	167	90.9	81.4	0.651	0.651	32.0	6,800	0.267
	169	90.9	81.4	0.798	0.798	38.5	5,450	0.327
	72	71.9	82.3	0.955	0.94	26.4	27.6	189.0
	70	71.9	82.3	0.955	0.93	33.8	36.4	217.5
	74	71.9	82.3	0.955	0.93	42.9	34.7	255.0
	75	71.9	82.3	0.955	10.52	51.9	32.5	285.0
	76	71.7	82.3	0.956	12.25	64.6	29.9	331.0
	77	71.7	82.3	0.956	12.95	76.7	28.1	376.0
	78	72.0	82.3	0.955	15.71	99.8	28.1	426.0
	79	72.1	82.3	0.952	17.35	113.1	26.2	471.0
	80	71.9	82.3	0.955	19.25	125.7	25.3	524.0
	81	72.9	82.3	0.930	21.4	144.1	24.9	585.0
	82	72.8	82.3	0.931	23.9	165.0	24.3	635.0
	83	73.9	82.3	0.931	24.9	214.0	24.0	692.0
	84	73.9	82.3	0.931	30.2	273.5	23.7	787.0
	85	73.9	82.3	0.931	31.9	322.0	22.7	847.0
	86	73.9	82.3	0.931	35.5	396.0	21.9	966.0
2. "Smooth" nickel saddles	142	86.1	80.7	64.9	0.187	10.05	23,100	0.0395
	144	86.0	80.7	65.1	0.207	14.22	19,820	0.0520
	146	86.1	80.7	64.9	0.272	19.65	15,150	0.0682
	149	86.3	80.7	64.7	0.424	32.9	10,370	0.1063
	154	86.0	80.7	65.0	0.772	58.7	5,900	0.194
	157	86.1	80.7	64.9	1.143	83.2	3,630	0.287
	159	86.2	80.7	64.7	1.553	108.7	2,670	0.390
	84	70.1	82.3	0.977	12.18	67.9	25.1	202.0
	85	70.1	82.3	0.977	13.44	81.0	23.1	221.0
	87	70.1	82.3	0.977	17.10	128.1	24.0	286.0
	89	70.3	82.3	0.974	20.6	162.3	23.5	346.0
	92	70.3	82.3	0.974	26.6	244.0	20.5	461.0
	94	70.3	82.3	0.974	33.2	402.5	19.97	556.0
	95	70.3	82.3	0.975	37.1	474.0	18.90	620.0
	96	70.3	82.3	0.974	41.0	557.0	18.21	686.0
	97	70.3	82.3	0.975	50.9	810.0	17.06	852.0
	44	144.5	60.5	0.277	28.6	200.0	15.87	1,367
	45	144.5	60.5	0.277	39.8	240.0	15.92	1,392
	46	144.5	60.5	0.277	51.6	273.0	14.78	1,538
3. Raschig rings	21	58.4	62.35	1.150	2.508	0.463	21.4	272
	22	58.6	62.35	1.147	3.118	0.596	20.5	328
	23	54.0	62.35	1.143	3.690	0.784	19.3	400
	25	59.0	62.35	1.140	4.74	1.210	18.1	516
	27	59.3	62.35	1.135	5.39	1.563	16.9	590
	29	59.5	62.35	1.132	6.54	2.01	17.3	684
	31	59.7	62.35	1.129	7.34	2.60	16.7	793
	33	59.9	62.35	1.126	8.33	3.40	16.5	917
	150	79.4	55.05	650	0.182	3.286	29,500	0.0446
	151	79.5	55.05	598	0.375	4.885	19,050	0.0670
	152	79.6	55.05	586	0.441	7.61	11,580	0.1083
	153	79.6	55.05	586	0.611	10.06	7,955	0.1502
	155	79.7	55.05	595	1.002	17.38	5,105	0.2462
	156	79.8	55.05	593	1.239	20.62	4,010	0.3049

\* See footnote on p. 415.

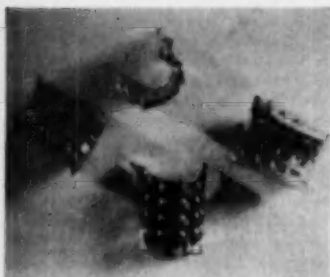


Fig. 6. Photograph of Protruded Nickel Saddles.

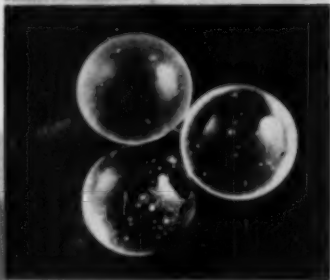
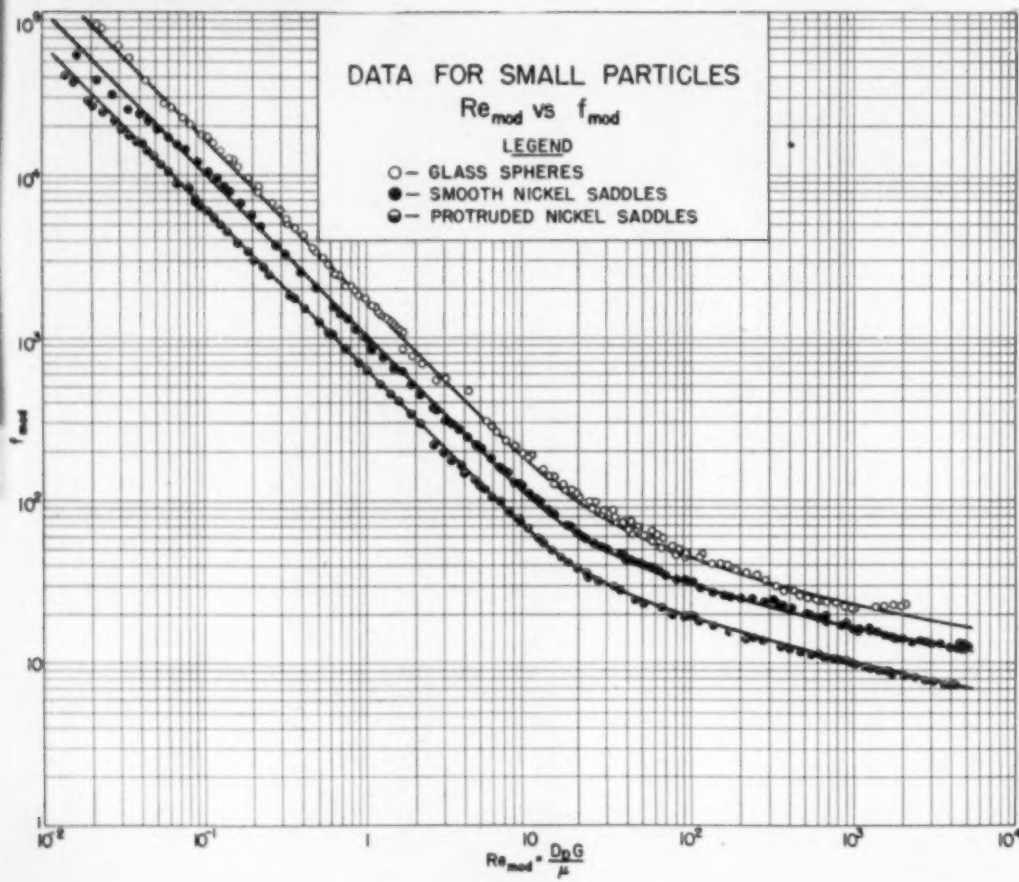


Fig. 7. Photograph of Glass Spheres.

not included in the revised correlation.

Data which cover a wide range of Reynolds numbers and porosity determine the values of the porosity functions with considerable accuracy. Values of these functions for the experimental data are single points in Figures 19 and 20. No data were taken in which porosity was varied for particles of a given shape, i.e., constant sphericity. Several parameters of constant sphericity, however, were established with the aid of the extensive data of Oman and Watson (8) in which porosity was varied. In constructing Figures 19 and 20 the authors' data were used to establish the spacing of the lines, and the data of Oman and Watson were used to set the slopes of the parameters. Additional parameters of sphericity were determined by graphically cross-plotting and interpolating between the parameters so established.

It is not always convenient to measure particle sphericity. Figure 21 is a plot of observed values of porosity and sphericity for randomly packed beds of uni-



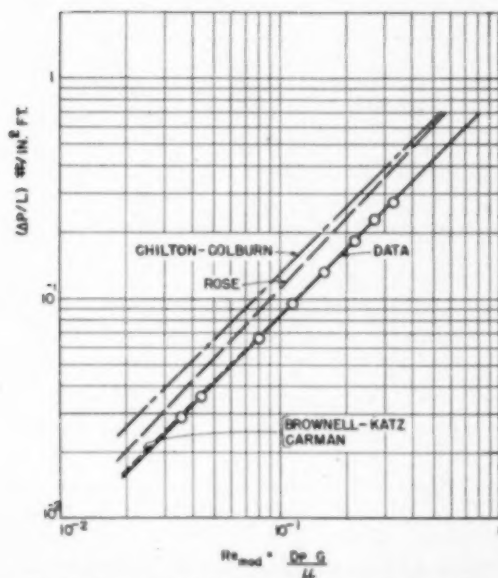
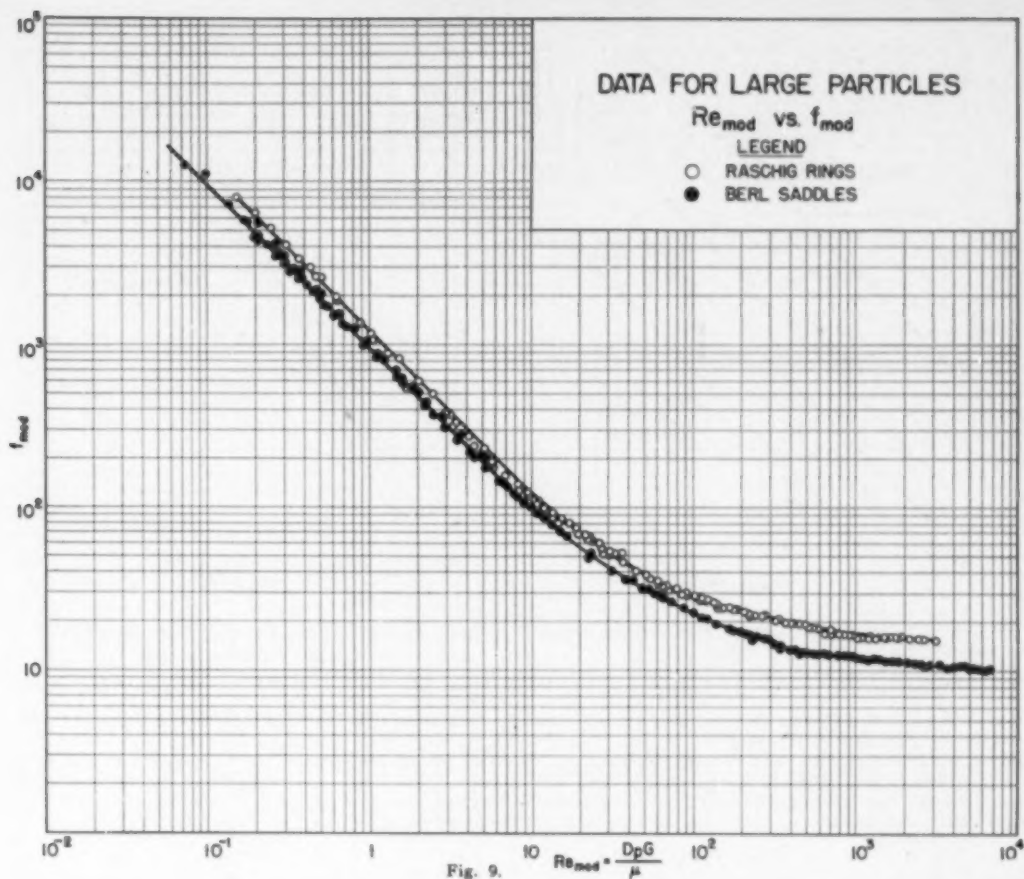


Fig. 10.  $Re_{mod}$  vs.  $(\Delta P/L)$ . Laminar Flow. Glass Spheres.  
 $X = 0.412$ .

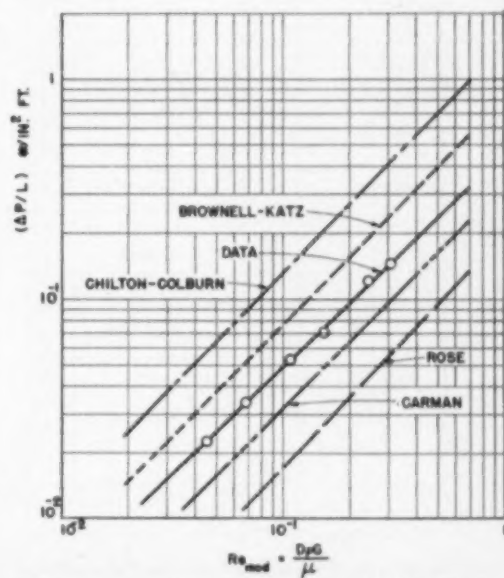


Fig. 11.  $Re_{mod}$  vs.  $(\Delta P/L)$ . Laminar Flow. Raschig Rings.  
 $X = 0.707$ .

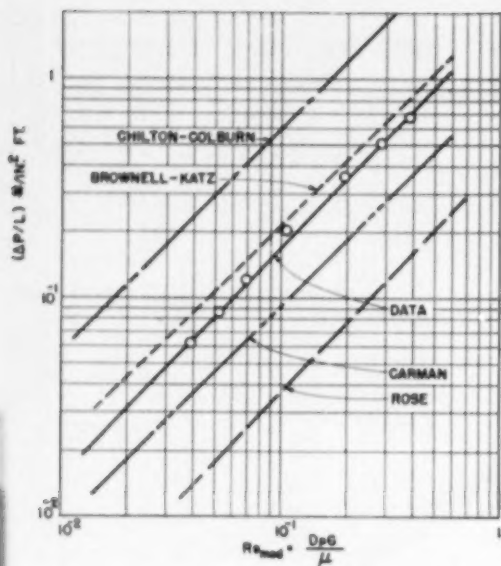


Fig. 12.  $Re_{mod}$  vs.  $(\Delta P/L)$ . Laminar Flow. Smooth Nickel Saddles.  $X = 0.931$ .

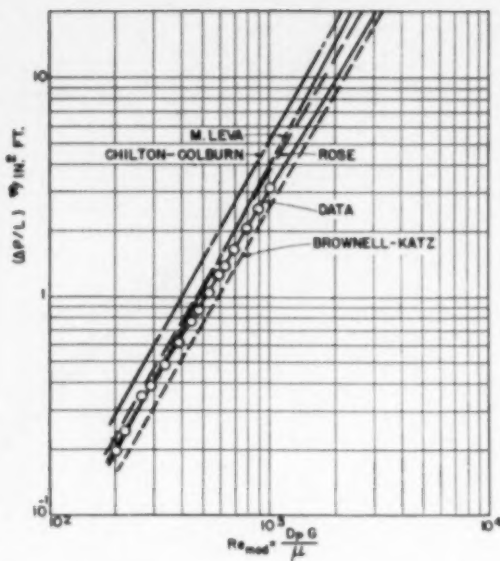


Fig. 13.  $Re_{mod}$  vs.  $(\Delta P/L)$ . Turbulent Flow. Glass Spheres.  $X = 0.412$ .

form-sized particles. It may be used to estimate particle sphericity provided the bed porosity is known. Since porosity is such a critical variable, it should always be measured. The relation shown in Figure 21 is recommended for estimat-

ing the sphericity of complex particle shapes, or in cases where there is doubt concerning the "effective" particle area and volume. The dashed line should be used for "normal" random packing, and values to the left or right used for dense-

or loose-packed beds, respectively. It is not advisable to use values of sphericity outside these bounds for predicting fluid flow even though the values are based on physical measurements (See discussion on splined rings, Part I).

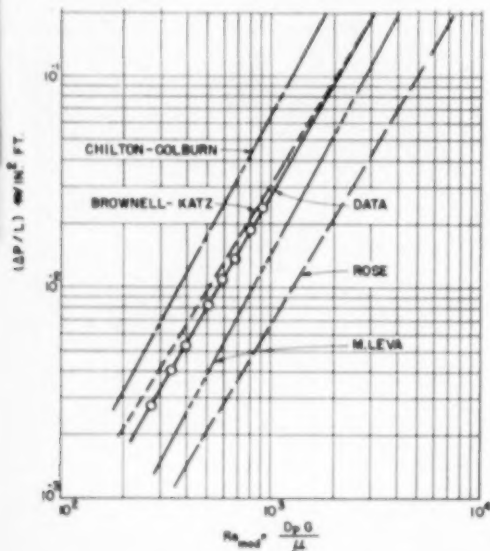


Fig. 14.  $Re_{mod}$  vs.  $(\Delta P/L)$ . Turbulent Flow. Raschig Rings.  $X = 0.707$ .

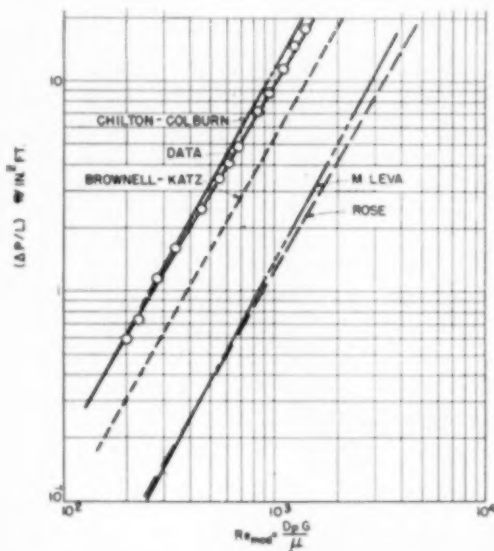


Fig. 15.  $Re_{mod}$  vs.  $(\Delta P/L)$ . Turbulent Flow. Smooth Nickel Saddles.  $X = 0.931$ .

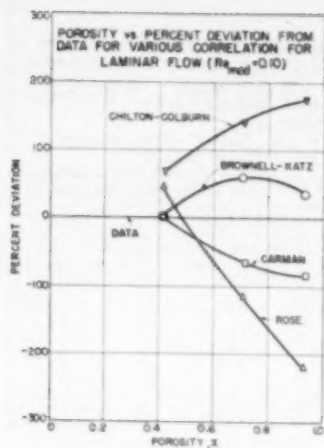


Fig. 16.

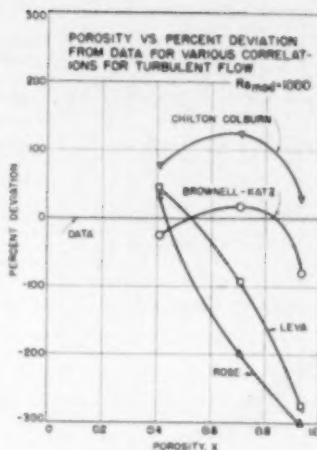


Fig. 17.

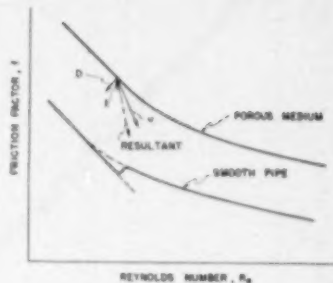


Fig. 18.

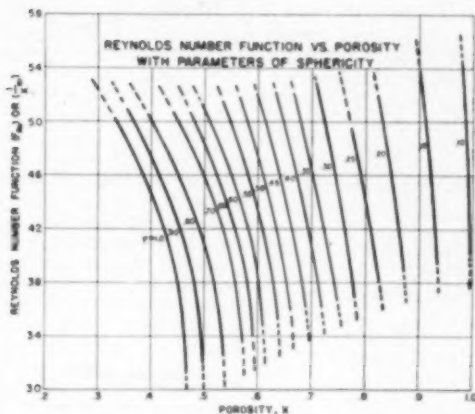


Fig. 19.

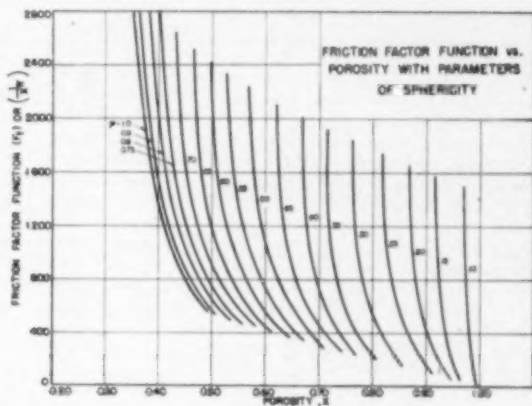


Fig. 20.

### Plot of Data Using Revised Correlation

As a check on the accuracy of this method of correlation, a range of data from various investigators (1, 3, 8) has been reduced to the pipe-plot using the porosity functions determined from Figures 19 and 20. The resulting composite of fluid-flow data is shown on Figure 22.

A maximum deviation of  $\pm 24\%$  and an average deviation of  $\pm 6\%$  from the curve for smooth pipe are representative of the results to be expected using this correlation.

**Example Problem.** It is desired to predict the pressure drop for the flow of air through

dense-packed  $\frac{3}{8}$ -in. MgO granules under the following conditions:

1. Container ..... 4-in. pipe ( $A = 0.0884$  sq.ft.)
2. Depth of bed ..... 0.737 ft.
3. Porosity of bed ... 0.427 or 42.7%
4. Pressure, inlet .... 14.7 lb./sq.in. abs.
5. Air temperature ... 80° F.
6. Air flow rate ..... 159 lb./hr.

Estimate: average density of air = 0.073 lb./cu.ft.  
viscosity of air = 0.018 cp.

The particle sphericity is estimated from Figure 21 on the line for dense-packing at  $X = 0.427$  as  $\psi = 0.745$ .

The Reynolds number and friction factor functions as read from Figures 19 and 20 at these values of  $X$  and  $\psi$  are, respectively:  $F_{Re} = 50$ , and  $F_f = 1700$ .

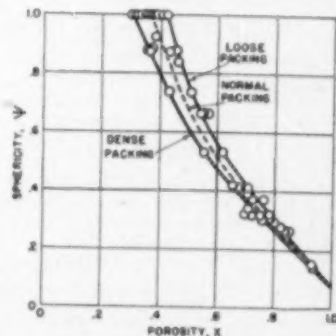


Fig. 21. Chart for Estimating Sphericity,  $\psi$ , from Porosity,  $X$ .



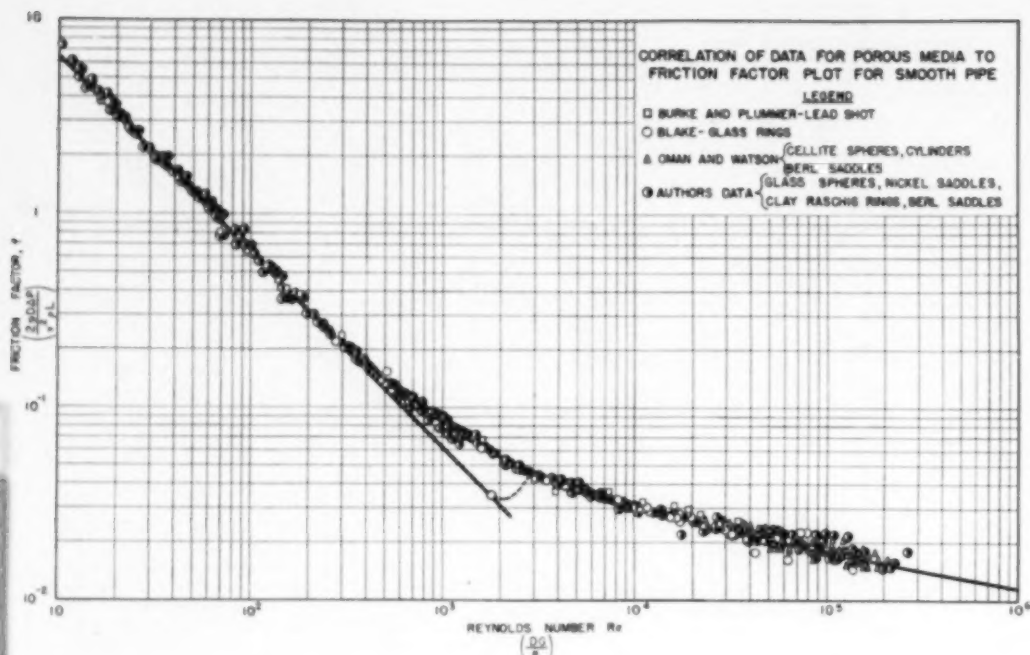


Fig. 22.

$$Re = \frac{D_p G F_{Re}}{\mu} = \frac{(3/16)(1/12)/(159)(50)}{(0.0884)(0.018 \times 2.42)} = 32,400$$

From the pipe-plot for smooth conduits, at  $Re = 32,400$

$$f = 0.0228 = \frac{2gD_p \Delta P}{L v^2 \rho} \times (1/F_f)$$

$$= \frac{2gD_p \Delta P}{L G^2} \times (1/F_f)$$

or

$$\Delta P = \frac{(0.0228)(159/0.0884)^2(0.737)}{(4.17 \times 10^6)(2)(0.073)(3/16 \times 1/12)} \times 1700 = 127 \text{ lb./sq.ft.}$$

Reported by Oman and Watson,

$$\Delta P/L = 185.5 \text{ lb./sq.ft. (ft.)}$$

or

$$\Delta P = 137 \text{ lb./sq.ft.}$$

Calculation is 7.3% low.

### Notation

$A$  = total cross-sectional area of bed, sq.ft.  
 $D$  = conduit diameter, ft.  
 $D_p$  = particle diameter, ft.  
 $f$  = friction factor, dimensionless

$$= \frac{2gD \Delta P}{L v^2 \rho} = \frac{2gD_p \Delta P}{L v^2 \rho}$$

$$\times X^* = \frac{2gD_p \Delta P}{L v^2 \rho} \times (1/F_f)$$

$f_{mod}$  = modified friction factor, dimensionless =  $\frac{2gD_p \Delta P}{L v^2 \rho}$

$F_f$  = friction factor function, dimensionless =  $1/X^*$

$F_{Re}$  = Reynolds number function, dimensionless =  $\frac{1}{X^*}$

$g$  = 32.2 ft./sec. (sec.) or 4.17  $\times 10^8$  ft./hr. (hr.)

$L$  = depth of bed, ft.

$m$  = exponent of porosity in Reynolds number term as used in Brownell-Katz correlation—Part I

$n$  = exponent of porosity in friction factor term as used in Brownell-Katz correlation—Part I

$\Delta P$  = pressure drop through bed, lb./sq.ft.

$Re$  = Reynolds number, dimensionless =  $\frac{D v \rho}{\mu} = \frac{D_p v \rho}{\mu}$

$$(1/X^*) = \frac{D_p v \rho}{\mu} (F_{Re})$$

$Re_{mod}$  = modified Reynolds number, dimensionless =  $\frac{D_p v \rho}{\mu}$

$v$  = velocity through conduit, superficial velocity of fluid through bed, ft./sec.

$X$  = porosity of bed, vol. voids/vol. of bed

$\mu$  = viscosity of fluid, lb./ft. (sec.)

$\rho$  = density of fluid, lb./cu.ft.

$\phi$  = particle sphericity, ratio of surface area of a sphere having the same volume as the particle to surface area of particle

### Acknowledgment

This work was made possible by a faculty research grant, Number M 653. Kameo Sugino assisted materially in the collection of data and calculations.

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# SONIC AGGLOMERATION OF CARBON BLACK AEROSOLS

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**A**EROSOLS are disperse systems of liquid or solid particles suspended in a gas. They may result from either dispersion or condensation processes. Particles of aerosols formed by dispersion processes, as for example by dry grinding, are usually larger than about 5 to 10 $\mu$  in diameter. Aerosols formed by dispersion are called dusts if formed by dispersing solids and sprays if formed by dispersing liquids. This type of aerosol is fairly easy to collect because of the relatively high settling rates of particles greater than 5 to 10 $\mu$  in diameter (about 0.5 cm./sec. for a 10 $\mu$  D spherical particle of density 2 g./cc. settling in air and 0.16 cm./sec. for a 5 $\mu$  particle). On the other hand, aerosols formed by condensation, called fumes if composed of solid particles or mists if composed of liquid particles, are less than about 5 to 10 $\mu$  in diameter and are extremely difficult to collect unless first agglomerated by one means or another. (The settling rate in air of a 1 $\mu$  D spherical particle of density 2 g./cc. is 0.006 cm./sec.)

It is not possible, of course, to draw a sharp line of demarcation between aerosols formed by dispersion processes and those formed by condensation processes. Aerosols of either type may contain a wide range of particle or agglomerate sizes. Condensation aerosols composed of solids are also called "smokes," as for example, the carbon smoke formed when a hydrocarbon burns with limited air supply. "Fog" is another term for liquid aerosols formed by condensation. Natural water fog, and artificial water fog formed when solid carbon dioxide is dropped in warm water, are examples.

Numerous review articles are available on aerosol behavior in general (9, 10, 23).

*Importance of Carbon Black Aerosol Collection Problem.* Collection of carbon black smoke, whether in the form

of furnace, channel, lamp or thermal black, is perhaps the most important single case in industry in which a fume or smoke is deliberately made and collected as product. The total United States production of all types of pigment and filler grade carbon black is more than 600,000 tons yearly. Nearly every type of fume-collection equipment yet devised has been used or seriously proposed for use in collecting carbon black. Channel black, like the black made from vegetable oils by the ancient Chinese, is collected by thermal precipitation on cooled surfaces, in this case the steel channels from which the process gets its name. Lampblack is collected in gravity settling chambers, and in some plants the residual smoke is scrubbed with water in a baffled spray tower (22) to recover additional quantities of black. Thermal black is collected in bag filters when it is made as a primary product and in water-filled traps and baffled spray towers when it is made as a by-product of oil-gas or hydrogen manufacture. Furnace black is agglomerated in Cottrell electrostatic precipitators and the agglomerates are collected in cyclones of conventional design.

It is in the furnace black industry that the most growth and technological progress are taking place today. Furnace black accounts for nearly half the total carbon black produced in the United States. Recently new grades of highly reinforcing furnace black have been developed that can replace channel black from both the quality and the economic standpoint. The United States produces about 90% of the world's supply of carbon black. There is little doubt that the furnace process will supplant eventually the channel process for producing all except certain special high-priced pigment carbons. This paper is concerned with the application of a new method of aerosol agglomeration to the furnace carbon black process.

*Description of Carbon Black Aerosols.* As initially formed in the partial combustion flame of the channel, furnace, or lampblack processes, or in the thermally cracked gas envelope of the thermal black process, carbon black consists of "primary" particles\* varying in number average diameter from about 0.005 to 0.5 $\mu$ . For a given type and grade of black the distribution of sizes about the mean is fairly narrow, i.e., about 90% of the particles of any given grade of black will lie within a 10-fold range of diameter. Furnace blacks range in mean diameter from about 0.03 to 0.07 $\mu$ . Figure 1 shows an electron microscope picture of semireinforcing furnace black before agglomeration by the Cottrell. Figure 2 shows the same black after passing through the Cottrell. The average primary particle size for this grade of black is about 0.07 $\mu$ . The tendency of the primary particles to form chain-like aggregates is strikingly shown by these pictures, which were made by catching carbon black smoke from a commercial unit directly on the resin-coated 2-mm. D 200-mesh screen used in electron microscope technique to hold the specimen. As far as is known, this has never been done before; all previously published pictures were made by redispersing collected carbon black by the dry sparking or the lacquer-grinding technique. Interesting as these pictures are, it is evident that the magnification is too great to give an over-all measure of agglomerate size distribution.

Soon after formation of carbon black nuclei and growth of these nuclei to form the primary particles, or concurrently with the formation of primary particles, the primary particles form

\* The primary particle is defined by the smallest particle that can be resolved by the electron microscope. The primary particle appears to be spherical in shape when viewed by the electron microscope. Primary particles are always more or less clustered together giving rise to such descriptive terms as "structure units" and "chain-like" aggregates.

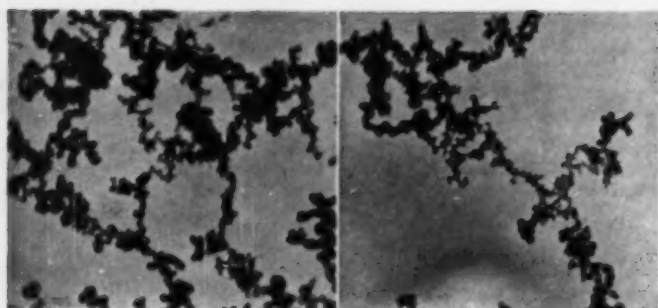


Fig. 1. Semireinforcing Furnace Black Before Cottrell Agglomeration (12,500 X).

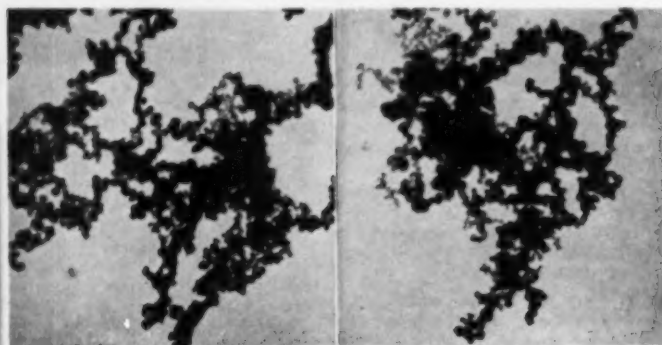
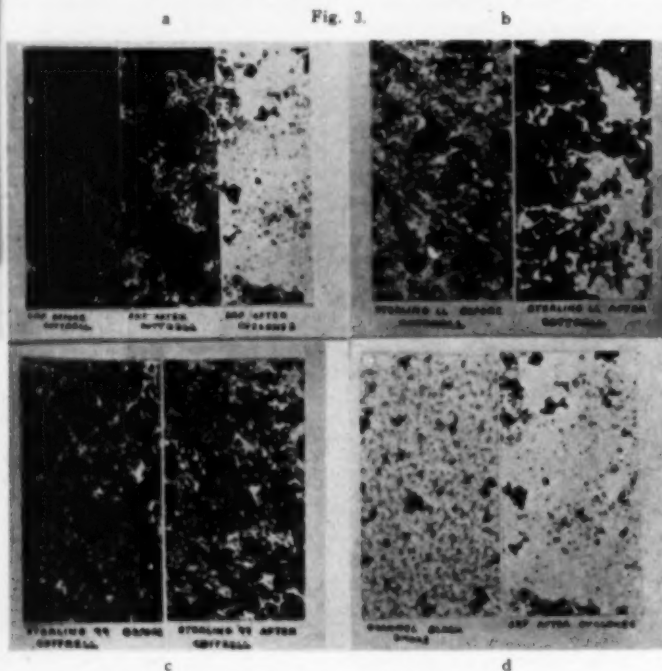


Fig. 2. Semireinforcing Furnace Black After Cottrell Agglomeration (12,500 X).



Photomicrographs Showing Agglomerating Effect of Cottrell Precipitators and Cyclones on Various Carbon Black Grades.

agglomerates,\* ranging in size up to well above  $10\mu$ . The left-hand panel in Figure 3a, b, c shows photomicrographs of these agglomerates for several grades of furnace black. Agglomerates considerably larger than  $5-10\mu$  may be formed when there is a sufficiently high initial concentration of primary carbon particles. Such large agglomerates are visible in the left-hand panel of Figure 3a. Quantitative data on the size distribution of agglomerates in carbon black smoke have not been published as far as is known. No good method of obtaining such data has been developed although there is considerable work under way on this type of sampling problem now (13, 20, 30). The agglomerate pictures shown in Figure 3 were made using samples caught on glass slides by quickly passing the slides through the smoke from commercial carbon black units.

In addition to a variable number of large ( $5$  to  $10\mu$  or more in diameter) agglomerates, there are many small agglomerates in a carbon black smoke that has not been subjected to some external agglomerating force. These small agglomerates, which are a large number fraction of the total agglomerates, are less than about  $5-10\mu$  in diameter so that they settle very slowly and cannot be collected at high efficiency in cyclones. The weight fraction of agglomerates less than  $5\mu$  in diameter seems to be a function of the total concentration of carbon black rather than a function of primary particle size of the black. It is the agglomerates below  $5-10\mu$  in diameter that present collection difficulties. (See Fig. 3.)

The range of effective agglomerate size is determined by inference from the fact that, in most cases, carbon black smokes settle only slowly unless agglomerated by a superimposed force, such as prevails in electrostatic precipitation, and from the fact that the agglomerates in carbon black smokes which have not been subjected to superimposed agglomeration forces are visible in the ordinary light microscope. These two facts indicate that a large portion of the smoke consists of agglomerates in the range of  $0.3$  to about  $5-10\mu$ . When a carbon black is formed under conditions that produce a high concentration of carbon particles in the smoke, particles may agglomerate rapidly enough to allow practical collection in gravity settling chambers. This is the case with lampblack made from creosote oil; the carbon black is formed just above the

\* The problem of determining what is a true agglomerate formed by chance collision of particles and agglomerates already formed and what is a structural or chain-like agglomerate formed integrally as a part of the carbon black primary particle growth process is unsolved.

surface of the vaporizing oil before the vapor is admixed to any great degree with the combustion air. Some small agglomerates of lampblack escape or are collected by secondary means but they are a minor weight fraction of the total black produced in this case.

**Methods of Agglomerating and Collecting Aerosols.** Aerosols formed by condensation processes usually must be agglomerated before the dispersed material, whether liquid or solid, can be separated out in a practical way. On the other hand, the coarser particles of aerosols formed by dispersion processes can be collected usually without a special agglomeration step. Devices for recovering the dispersed particles of aerosols may be divided into two groups according to their principal function:

1. Agglomerating
  - a. Electrostatic precipitators
  - b. Sonic agglomerators
2. Collecting and agglomerating
  - a. Gravity settling chambers
    - (1). Without contact surface
    - (2). With contact surface
  - b. Inertial separators, dry or wet
    - (1). Centrifugal type
    - (2). Impingement type
  - c. Barrier devices (filters)
  - d. Thermal precipitators
  - e. Interphase transfer devices (scrubbers using liquids as collection medium)

These devices having agglomeration as a principal function are usually followed by devices having collection as a principal function, although this is often unnecessary in case of electrostatic precipitators when operating on high specific gravity solid aerosols or on liquid aerosols that collect on the electrodes or agglomerate in the space between electrodes and fall into the hopper without being reentrained in the gas stream. Also in the case of extremely dilute aerosols, an electrostatic precipitator may function primarily as a collection device. In such a case the particles of the aerosol are moved, with little chance of agglomeration because of the large spacing between particles, to the discharge electrode where they adhere to a dry- or wet-collector plate. An example is the Precipitron used to remove dust from air in air conditioning installations. It is worth noting that in all of the aerosol-collection devices agglomeration (cohesion) and adhesion play an important part in the proper functioning of the apparatus. For example, a bag filter will collect fairly dilute carbon black smoke even though the agglomerates are much smaller than the pores in the filter cloth. The carbon agglomerates adhere to the fibers and then other carbon agglomerates cohere to the car-

bon adhering to the fiber. In this way a filter cake of carbon is built up that is impermeable to even the smallest carbon agglomerate. If the carbon black smoke is too dilute, the carbon penetrates the fabric to such an extent that it not only plugs it completely but also destroys its flexibility to a large degree.

There are many practical reasons why furnace black aerosols should be agglomerated before an attempt is made to collect them. Suffice it to say here that furnace black collection is a two-step process: agglomeration followed by collection.\*

In view of this statement it may be somewhat puzzling that thermal blacks are collected in bag filters. The answer is that thermal blacks are produced in a cyclical process and are collected in an atmosphere containing 80% or higher concentration of hydrogen. Furthermore, the pigment and filler grade thermal blacks (as contrasted with by-product grades) are much more economical to handle when collected dry. A bag filter is about the only practical device yet developed that will meet all the above-mentioned conditions.

The electrical precipitator (Cottrell) functions well to agglomerate furnace blacks and is used today in all furnace black plants. However, it is a high first-cost apparatus and suffers somewhat from lack of flexibility when switching from one grade of furnace black to another and/or to different flow rates. It must be shut down for frequent cleaning of the electrical system and is sensitive to electric surges due to lightning storms or other causes. Power consumption for energizing the electrodes and for pump-

\* However, in at least one case a unit is being built to both agglomerate and collect carbon black in an electrostatic precipitator. Collection efficiencies of  $96\% \pm 2\%$  at an inlet grain loading of 2.2 gr./cu.ft. are confidently expected by the builder (18).

## SCHEMATIC DRAWING OF SIREN OR VALVE TYPE SOUND GENERATOR

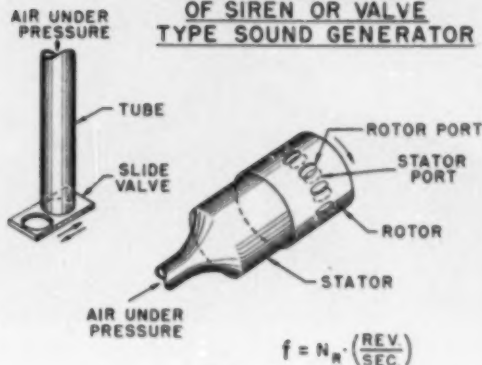


Fig. 4.

ing gas through the precipitator is low. Cost of the cyclones used in conjunction with electrostatic precipitators is relatively low compared with the cost of the precipitator and auxiliaries.

Because of the growing importance of furnace black, the increasing difficulty of collecting finer particle-size blacks due to the low total black concentration in these cases, and the great increase in construction and equipment costs with a corresponding increase in natural gas value, it is only logical that some effort would be made to develop agglomeration apparatus of lower first cost and of equivalent or superior performance compared with the electrostatic precipitator.

This paper presents the results of the first (as far as is known) fairly large-scale experimentation, using actual commercial conditions, with sonic energy as a means of agglomerating an aerosol, which in this case was so-called "fine" furnace black. Because of the pioneering nature of the work, many questions were left unanswered. However, many have been partially answered by subsequent commercial-scale tests on other aerosols. It has been concluded as a result of the experiments described here and subsequent commercial tests, that the next step in applying sonic agglomeration to furnace black, might well be a full commercial-scale unit involving a gas flow of 30,000 cu.ft./min. or higher. Data on sonic agglomeration presented later in this paper represent some of the first development work done by the Ultrasonic Corp. and should not be taken as indicative of the present state of the art, since considerable development has taken place since.

### Sonic Agglomeration

*Apparatus For Generating Sound in Gaseous Media. Three types of appa-*

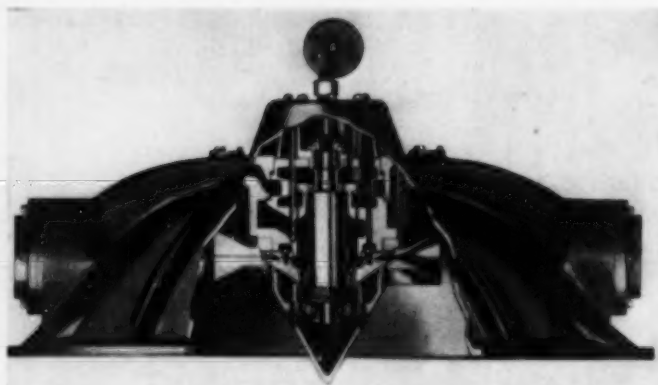


Fig. 5. Cutaway View of the Ultrasonic Corp.'s U-2 Siren-type Sound Generator.

raturs are used to generate sound in a gas:

1. Piston
2. Valve (siren)
3. Gas current (whistle)

Various types of sound generators have been reviewed by Sollner (29). The piston type includes crystals that vibrate by the piezoelectric effect, magnetostriction devices, and electromagnetic devices. Other methods of actuating a piston, e.g., a purely mechanical system for vibrating a piston or diaphragm, may be visualized. It is sufficient to say here that as yet no one has developed a piston device practical for generation of high intensity sound on large scale in gases. St. Clair (24) used an electromagnetic device on a fairly large laboratory scale in studies on agglomeration of

ammonium chloride and other smokes.

A satisfactory piston-type sound generator for commercial use in gaseous systems would present an advantage over the valve type in that there would be no dilution of the gas being treated when using the piston-type generator.

In valve-type sound generators, a flowing gas stream is interrupted at a high frequency by a suitable valve arrangement. The simplest case would be that of a tube (See Fig. 4) where the air discharge is interrupted at regular frequency by a slide valve. In order to get high frequencies a siren design is employed commercially in which there are  $N_R$  stator holes and  $N_R$  rotor holes. At a given speed of revolution (rev./sec.), the frequency of the sound is given by:

$$f = N_R(\text{rev./sec.})$$

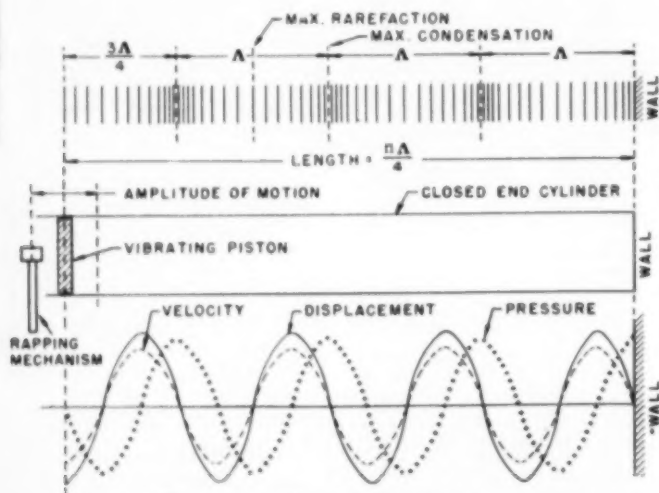


Fig. 6. Sound Effect in Resonant System.

The valve-type sound generator always involves dilution of the gas being treated by the gas passing through the valves of the generator. Use of separating diaphragms between the sound source and acoustic chamber is not yet practical on a large scale.

In practice, a siren-type generator is driven by a variable-speed electric motor or a turbine. This type of generator can be driven by the rotor gas supply if the rotor and stator are designed properly. However, an external drive is needed for good control. The principal power input is the power required to compress the rotor gas. The rotor gas supply is at pressures up to about 5 or 6 lb./sq.in. gage. Higher pressures may be used, giving higher intensities of sound, but with existing siren-generator designs, above 5 or 6 lb./sq.in. gage, a small gain in sound intensity is at the expense of a large decrease in efficiency. At constant speed and rotor pressure, the total sound energy output is proportional to the total area of the rotor ports. Figure 5 shows a cut-away view of the Ultrasonic U-2 siren-type sound generator used for the work described in this paper.

The problems of design and operation of siren-type generators are similar to those encountered in high-speed turbine design and operation. Hence it may be concluded that such generators can easily be made practical commercial devices, a conclusion now borne out by commercial-scale operation in at least two cases (21).

Gas current or whistle-type sound generators have been described in the literature (17). These devices have not been developed to high enough efficiency to be of practical importance in commercial sonic agglomeration. An organ pipe is an example of a low intensity whistle-type sound generator.

**Effects of Sound Energy on Aerosols.** Agglomeration of aerosols by sound energy has been studied more thoroughly with a view toward practical use than any other action of sound waves on colloidal systems. The state of knowledge up to 1944 has been well summed up by Sollner (28):

Numerous attempts have been made to apply sonic coagulation methods to the precipitation of industrial fogs and smokes. Since coagulation occurs readily in streaming aerosols it is possible to handle large volumes; however, no definite statement can be made at present as to whether or not sonic coagulation may be developed into an industrial method; the chances that this may be achieved seem to be rather good.

Up until 1946, when Horsley and associates of Ultrasonic Corp. developed their high output siren, no practical



device was available for generating high intensity sound in gases on large scale so that prior to 1946 laboratory findings on sonic agglomeration could not be followed up by pilot plant or commercial-scale tests.

The theory of the agglomerating effect of sound is qualitatively well developed but quantitative calculations of agglomerating effect under commercial conditions cannot yet be made. It has not been definitely established which of the several mechanisms of agglomeration is most important under a given set of circumstances.

Figure 6 shows an idealized system in which the gas in a closed-end sound chamber is in resonant vibration with a source of sound waves, in this case a vibrating piston-type sound generator. The length of the chamber is related, at resonance, to the wave length of the sound by

$$L = \frac{n\lambda}{4}$$

where  $L$  is the chamber length,  $\lambda$  is the wave length of the sound, and  $n$  is any odd integer. The top line of Figure 6 shows schematically the condensation and rarefaction of the gas at any instant, and the bottom line shows (the curve designated by crosses) the corresponding instantaneous pressure as a function of length. The points of maximum condensation and rarefaction will be reversed each cycle, but the points at which the pressure curve crosses the reference axis remain the same. The gas velocity and displacement curves are in phase with each other and are a quarter-wave length out of phase with the pressure curve. The points where the curves cross the neutral axis are called nodes; the maxima of the curves are called antinodes or loops.

At a given frequency of rapping, the energy input to the chamber remains constant if the amplitude of the piston is constant. At a given frequency, if the rapping is made more vigorous, the amplitude of the piston increases and the energy input to the chamber increases as the square of the amplitude. The energy input at constant amplitude increases as the square of the frequency.

It is clear that in the resonant system described there must be sound energy losses equal to the energy input at the piston or the amplitude of the piston would increase each time the sound wave reflected from the end of the chamber back to the piston. In practice there are at least four ways in which the sound energy will be dissipated:

1. Absorption at the wall and transmission through the wall
2. Damping due to viscous (frictional) effects in the gas
3. Losses through openings (in case of flow systems)
4. Absorption of energy in causing the aerosol particles to move (ultimately appears as a frictional effect in the gas)

Each time a sound wave strikes a rigid wall of smooth material (surface discontinuities small compared with the wave length), the energy of the reflected wave is about 99% of the energy of the incident wave, a loss on the order of 1% (effect 1). About 10% of this effect can be accounted for as needed to accelerate the molecules of

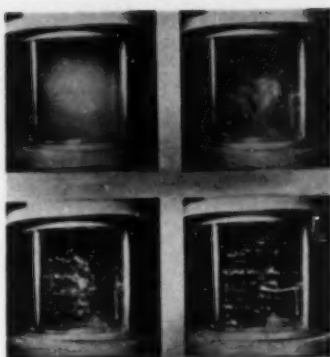


Fig. 7. Successive States of Agglomeration of  $\text{NH}_4\text{Cl}$  Smoke in St. Clair's Apparatus (27)

the wall construction material and about 90% cannot be explained readily. Since this loss occurs each time the wave strikes the wall, the total loss by this mechanism can be appreciable. The second effect is small at low frequencies (on order of 1000-10,000 cycles/sec.) with low molecular weight gases at ordinary pressures and temperatures. Effects 1 and 3 are the major effects in practical commercial systems, i.e., flow systems. It may be possible to reduce effect 3 by installing acoustic filters of suitable design. Effect 4 is the useful effect and is believed to be of appreciable magnitude, although no one has succeeded in measuring it with high precision.

The intensity of sound energy is measured by

$$\frac{\text{energy}}{(\text{unit time})(\text{unit area})}$$

in the direction perpendicular to the travel of the wave. A common unit of intensity is watts/sq.cm. or

$$\frac{\text{ergs}}{(\text{sec.})(\text{sq.cm.})} \times 10^7$$

The decibel notation is also used to designate intensity. The number of decibels between two intensity levels is 10 times the log of the intensity ratio:

$$N = 10 \log \frac{I_1}{I_2}$$

where  $N$  is the decibel rating corresponding to the intensity  $I_1$ . On this scale, the faintest sound of frequency 1000 cycles/sec. discernible by the normal human ear corresponds to an absolute energy intensity of  $10^{-16}$  watts/sq.cm. and to a pressure effect of 0.0002 dynes/sq.cm. Thus for an intensity of 160 decibels, the absolute intensity is:

$$I_1 = I_2 \left( \text{antilog } \frac{N}{10} \right) = 10^{-16} \cdot 10^8 \\ = 1 \text{ watt/sq.cm.}$$

Another term of significance in acoustic systems is the energy density, usually expressed in ergs/cu.cm.

Brandt, Freund and Hiedemann (5, 7, 12) have studied by means of high speed microphotography the motion of aerosol particles in a sound field and

have published microphotographs of the aerosol before and after agglomeration. These same authors (1-4, 6, 8) and others (15-16, 17, 19, 31) have discussed the movement of suspended particles in a sound field and have developed mathematical relationships to describe particle motion.

Recently St. Clair (25, 26, 27) has published the results of a series of experiments on sonic agglomeration of ammonium chloride smokes. He shows by photographic evidence (Fig. 7) that the agglomerated aerosol collects in regions spaced  $\frac{1}{2}$  wave length apart, corresponding to nodes or antinodes, and concludes that the radiation-pressure effect is of controlling importance in causing agglomeration.

It is recognized that at least three mechanisms are operative in causing agglomeration of an aerosol in a sound field:

1. Covibration of particles in the vibrating gas as a result of the drag between particles and dispersion medium. This causes an increased rate of particle collision.
2. The Bernoulli effect due to the constriction or expansion of the dispersion medium as it moves rapidly back and forth between or parallel to closely spaced particles.
3. The radiation pressure effect arising because of difference in momentum of the dispersion medium on opposite sides of the particle.

In a carbon black aerosol during and immediately after formation, the particles are subject to Brownian motion,\* which brings about a rapid rate of collision between particles until the agglomerates so formed either become too large to be affected by the impacts of the molecules of dispersion medium or become too far apart for frequent collision. When this stage is reached, the aerosol is relatively stable and will settle only slowly under the influence of gravity. Channel black smoke, for example, will remain suspended on the horizon for days at a time when there is little turbulence in the air below a few thousand feet above the ground. The particles of a stable aerosol may be protected from agglomeration by a repulsion effect if all particles bear electric charges of the same sign. The particles or the agglomerates are surrounded by a stagnant layer of gas that may tend to reduce the number or the effectiveness of the collisions between particles and agglomerates. The adsorption of gas in a thin layer on the surface of the particles is thought to make agglomeration more difficult.

\* This effect is greatly enhanced by the high temperature of the furnace process, which increases greatly the kinetic energy of the dispersion medium molecules.

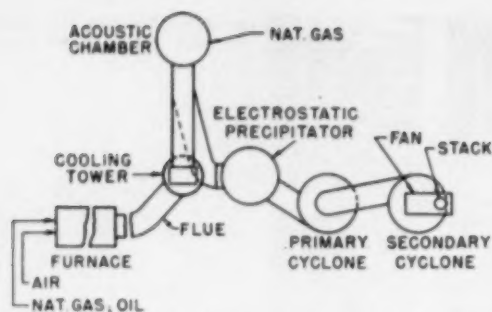


Fig. 8. Flow Diagram for Sonic Agglomeration Experiments.

If a stable aerosol is passed through a sound field of high intensity, the aerosol particles are moved back and forth at the frequency of the sound and at a velocity varying with the size of the particle but always less than the velocity of motion of the dispersion medium. (This is mechanism 1 just described.) The largest particles move little because of their high ratio of mass to drag; the smallest particles move almost at the velocity of the dispersion medium. The higher the intensity of the sound the greater the rate of acceleration of the particles and hence the greater the en-

ergy of the impact between particles. For each size of particle there is an optimum frequency of sound, at a given sound intensity, that will produce the greatest degree of motion of the particle. However, because of the broad size distribution of particles and agglomerates, the range of optimum frequency may be rather broad. It is quite probable that this motion effect is of controlling importance in the agglomeration of carbon black aerosols when subjected to a sound field for only a few seconds, as would be the case in any commercially practical apparatus. It does not seem likely

that the radiation-pressure effect would be the major cause of agglomeration when the contact time is low (less than 2 or 3 sec.).

The Bernoulli effect is of importance only when particles are quite close together. When the line of centers of the particles is at right angles to the sound field, the particles are attracted. When the particles are arranged with their line of centers parallel to the sound field, the particles are repelled.

The radiation pressure in a sound field may be measured by suitable delicate instruments. Its magnitude may also be calculated (14). Radiation pressure is demonstrated by the fact that a standing wave sound field in a gaseous medium will support objects of considerable size, e.g., a ping-pong ball or a fifty-cent piece.

#### Description of Apparatus and Procedure

**Laboratory Apparatus.** The first experiments were made in a Pyrex glass jar into which sound was transmitted through a stretched rubber diaphragm about 1 mil in thickness. This jar, which held about one-half cubic foot of smoke, was flushed with carbon black smoke until all the original air was displaced. The inlet and outlet were then closed and sound directed against the diaphragm. Agglomeration was followed qualitatively by changes in intensity of transmitted light measured with a photocell. All measurements were relative as no calibration of light transmission vs. agglomerate size could be made. Studies of light transmission vs. time were made for carbon black smoke without sound and with sound of varying frequencies and intensities. No continuous flow experiments were made.

From the start the laboratory experiments were beset by all manner of difficulties. The principal difficulty was that of carbon black precipitating on the walls of the glass jar, which interfered with the light transmission readings. This difficulty can be overcome in a flow system by suitable means but in a batch system it can only be minimized, not eliminated, by keeping the smoke temperature the same as the temperature of the glass, thus avoiding the thermal-precipitation effect.

The carbon black smoke was made by burning natural gas; to avoid condensation of water vapor on the chamber walls, the smoke was passed through a Dry-Ice trap to remove water vapor. This meant that there probably was a fog of water droplets mixed with the carbon black particles making agglomeration of the carbon black easier.\* Hence the laboratory experiments did not closely duplicate expected commercial conditions. The rubber diaphragm made experiments at temperatures above the smoke dew point impossible even if wall condensation could have been avoided.

Sound intensity was measured in the empty chamber using a microphone device of conventional construction. The precision of this measurement is low. It is interesting

\* Experiments on agglomeration of artificial water fog showed that fog agglomerated more readily than carbon black smoke under comparable conditions. Theory indicates that water fog mixed with the smoke would greatly assist the agglomeration of the latter.

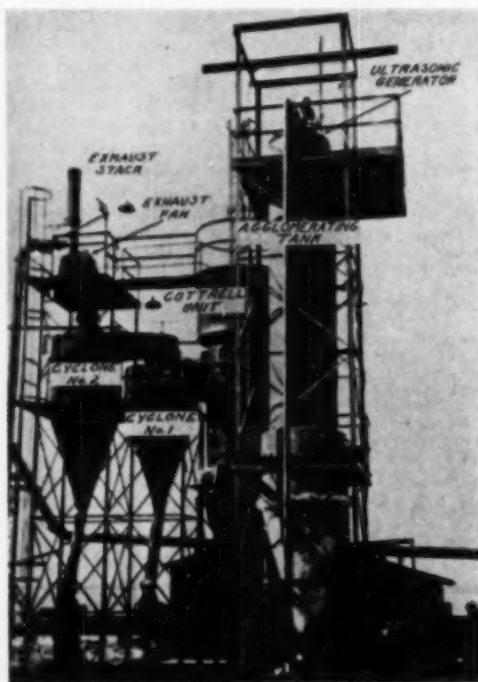


Fig. 9. Pilot Plant Sonic Agglomeration Apparatus.

to note that a microphone makes use of the piezoelectric effect to measure sound intensity, and it will be recalled that the piezoelectric effect can serve also as a source of sound, e.g., quartz crystal sonic generators.

Sound was generated by an Ultrasonic Corp. U-1 siren-type generator driven by compressed air. This model of generator is now obsolete.

It was concluded that the laboratory experiments were of little value in judging the practicability of commercial sonic agglomeration of carbon black, although the laboratory experiments did demonstrate the pronounced agglomerating effect of sound at the 150-db. level. Hence it was decided to go to pilot plant scale in further experimentation.

**Pilot Plant Apparatus.** For pilot plant work a sonic agglomerating system was installed in parallel with a Research Corp. electrostatic precipitator (Cottrell) in an existing furnace black pilot plant (See Figs. 8 and 9). Figure 10 shows a commercial Cottrell cyclone system of 50,000 cu.ft./min. rated capacity. The similarity of pilot plant and commercial apparatus is evident. The rated capacity of the pilot plant Cottrell-cyclone system is 3500 cu.ft./min. at flow conditions, although this rated capacity has little significance since it must necessarily be based on some arbitrary degree of collection of a certain type of black at a specified range of inlet grain loadings.\*

Since the smoke passed in series through the sound chamber and the Cottrell, it was possible to test one or the other or the two in series for agglomerating the smoke produced under any given set of furnace conditions.

Fine furnace blacks were produced in the furnace using commercial burners and commercial fuel-air ratios so that the smoke produced was accurately representative of commercial conditions. The primary particle size and grain loading of the carbon black smoke could be varied more or less independently over a rather limited range by varying the degree of oil enrichment of the natural gas serving as the primary fuel. The smoke temperature could be adjusted by water sprays in the cooling tower down to about 100° F. above the dew point. Lower temperatures caused condensation difficulties in the agglomeration and collection system. The rate of smoke delivery to the sound chamber was about 1000-1200 cu.ft./min. at chamber conditions.

The sound generator was the Ultrasonic Corp. type U-2 driven by a turbine powered with high pressure natural gas. Natural gas was used as the rotor fluid in amounts averaging about 1000 cu.ft./min. measured at 14.7 lb./sq.in.abs. and 60° F. Thus the dilution of the smoke by the rotor gas was about 1 to 1, which presented a serious disadvantage to obtaining data truly representative of expected large-scale commercial conditions (volume flow rates of 20,000-65,000 cu.ft./min. at 450° F. and atmospheric pressure are common on commercial scale). The smoke entered the sound chamber near the top and left near the bottom. The sound generator was mounted at the top of the chamber. Figure 11 is a drawing to scale, except for height, of the sound chamber. Little black collected in the sound chamber. Most of the ag-

\* This particular Cottrell-cyclone system is rated to collect 90% or more of semi-reinforcing furnace black at a flow of 3500 cu.ft./min. (450° F., 1 atm.). The inlet grain loading for this type of black is approximately 5 gr./cu.ft. at flow conditions.

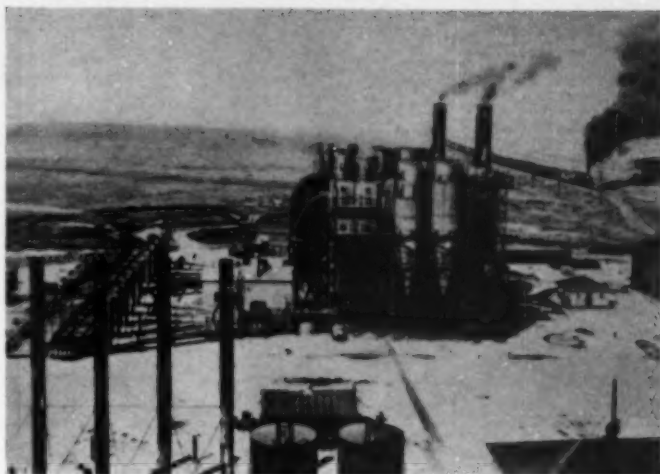


Fig. 10. Commercial Furnace Black Plant with Cottrell-cyclone Collection System.

glomerated black was swept along with the gas stream and collected in the two cyclones. It was interesting to observe that no carbon collected on the walls of the chamber as would be expected. Apparently the vibration kept the surface clean. Grain-loading tests by the Research Corp. method were made at agglomerator inlet and stack outlet on most runs. The total black collected in sound chamber, precipitator and cyclones was accurately weighed on each run. Collection efficiency could be calculated either from the stack loss or from the difference between the known carbon input to the agglomerator and the black collected. For a given set of furnace conditions the carbon yield was accurately known from previous experiments. The flows of natural gas, air, and oil to the furnace were measured, the gas and air on recording meters

and the oil by gaging tanks. The water vapor content of the smoke stream entering the agglomerator was measured by condensing the water vapor down to a given dew point in a metered volume of gas. The water collected plus that calculated to be in the saturated gas gave the total water content. The rotor gas supply and generator revolutions per minute were measured. The turbine gas supply was not metered but the inlet pressure was recorded. A previous calibration gave the relation of gas flow through the turbine and revolutions per minute as a function of inlet pressure.

Sound intensity measurements were made with a microphone when no smoke was passing through the chambers; the microphone could not be used in the smoke because of the high temperature. The sound

#### SONIC AGGLOMERATION CHAMBER

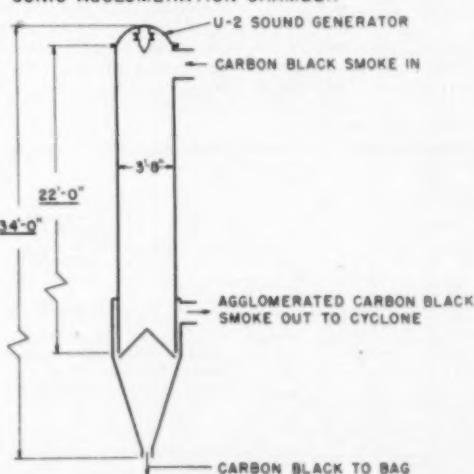


Fig. 11.

TRANSMITTED LIGHT INTENSITY VS TIME  
(MEASUREMENT OF DISPERSION IN TEST CHAMBER)

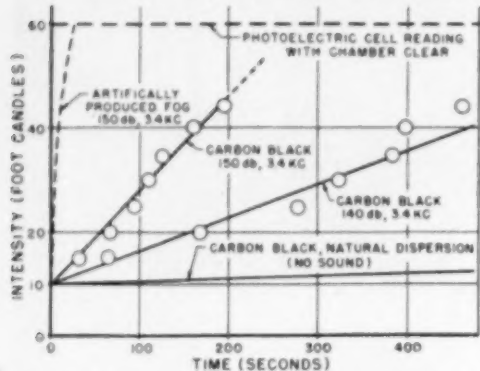


Fig. 12. Effects of Sound at Two Different Intensities on Clearing Carbon Black Smoke.

intensity measurements were not traverses but measurements of average maximum intensity. Later experience in sound measurement has indicated that the over-all average intensity corresponding to the average maximum readings obtained would have been about 155 db., and this figure is used with the data in this paper. If the intensity could have been measured with smoke in the chamber it would have been found lower than in the empty chamber because of the absorption of sound energy in moving the aerosol particles.

Theoretical power input could be calculated as that available from expanding turbine and rotor gas reversibly down to the sound-chamber pressure (13.2 lb./sq. in. atm. p.). No method has been devised as yet to measure the acoustic power output of a siren-type sound generator in an enclosed field. Hence there is no way of computing the efficiency of conversion to acoustic energy of the total energy input to the system. Measurements made in a free field indicated efficiencies for this type generator in the range of 10-50% depending upon operating conditions and design.

Summing up the significance of the measurements that could be made with the pilot plant apparatus: Carbon black

smokes of a limited range of primary particle size and grain loading could be subjected to sound intensities of not greater than about 155 db. for a limited range of contact times. Dilution of the smoke by rotor gas was about 1 to 1. The degree of collection of the sonically agglomerated smoke in a cyclone system of arbitrary design (not the design for optimum collection) could be measured and observation of the smoke itself could be made to discover qualitatively the degree of agglomeration.

### Results

**Laboratory.** Significant laboratory data are summarized in Figure 12. These data show the effects of sound of two different intensities on clearing carbon black smoke. For comparison, a blank run was made in which carbon black smoke was allowed to stand without sound treatment. The curve for agglomeration of water fog is shown in Figure 12 also.

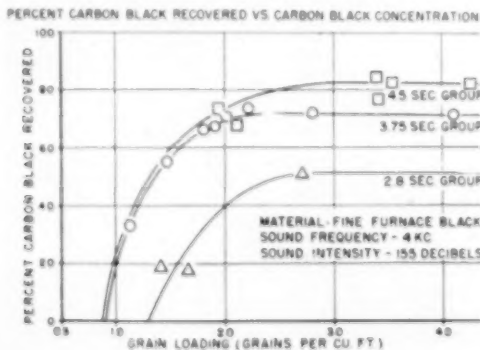


Fig. 14.

SOUND INTENSITY APPROX. 155 DECIBELS  
FINE FURNACE BLACK, 92 SCALE, 2 GR./FT.<sup>3</sup>

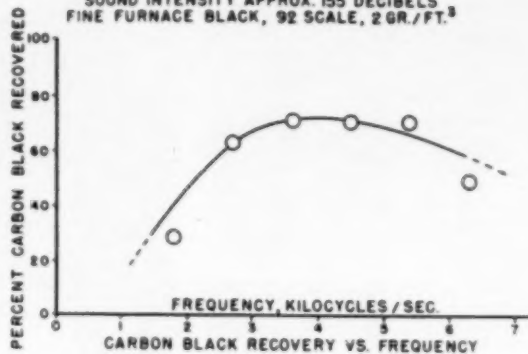


Fig. 13.

An attempt was made in the laboratory experiments to find the optimum sound frequency for carbon black agglomeration but the results were inconclusive and the data are not presented here. It was estimated from the laboratory data on carbon black smoke and artificial water fog that the frequency range 3000-4000 cycles/sec. would be optimum for carbon black.

Laboratory data served merely to show that sound energy at intensities in the range of 145-150 db. and at frequencies of the order of 3000 cycles had a pronounced agglomerating effect on carbon black smoke that had been dehumidified and cooled to near room temperature. Rough tests gave the disturbing indication that smoke which had not been passed through a Dry-Ice trap for cooling and dehumidification would not agglomerate as well as smoke that had been so treated but the practical significance of this difference could not be judged.

**Pilot Plant.** Because of the pioneering nature of the work, the experimental setup, as well as the data obtained, was far from satisfactory for obtaining good commercial design data. Many variables could be measured only with limited precision. Grain-loading tests were particularly tedious and limited in precision. Some variables could not be measured at all, for example, the efficiency of conversion of the energy in compressed natural gas to sound energy. On the other hand such trends as could be observed can be relied upon beyond all reasonable doubt since enough data were obtained to give consistent and reasonable curves.

Figure 13 shows a series of runs made to determine the optimum sound fre-

quency for carbon black agglomeration. While these data substantiate the laboratory data in showing an optimum frequency in the range of 3000 to 5000 cycles/sec., it is believed that the frequency effect is complicated by the characteristics of the sound generator. The optimum frequency may be due as much to the higher efficiency and higher sound intensity of the generator at certain frequencies as to the existence of a true optimum frequency range for agglomeration in the ranges studied.

Figure 14 shows the best of the basic data on collection of a given-type black vs. grain loading and contact time, frequency and intensity remaining constant. These data could be roughly verified by an experienced observer looking at the stack and this verification served as a check against gross errors in collection efficiency measurements.

An interesting observation was made by dipping a glass slide quickly into the smoke entering the sound chamber and comparing this slide at a magnification of 100 with a slide obtained in a similar manner on the agglomerated smoke at the sound-chamber outlet. The change in degree of agglomeration is striking. In the agglomerated smoke the small agglomerates have been almost completely eliminated. The method of sampling is open to some question in that the larger agglomerates would be caught more easily than the smaller ones. However, in view of the relatively low velocity of the smoke and the rapid insertion and removal (in 2 or 3 sec.) of the slide normal to the smoke flow, it would seem that a representative sample would be obtained. The slides were examined carefully over the entire area of deposited smoke to get a representative field for photographing.

No mechanical difficulties of any consequence were experienced with the sound generator but no extended runs (over about 8 hr.) were made. The noise level was not great and no strong complaints were voiced by the operators. The high-pitched whine seemed to have a slightly annoying psychological effect. The chamber was not insulated or otherwise specially equipped to cut down on the intensity of the escaping sound.

### Discussion of Results and Conclusions

*Measured Collection Efficiency of Sonic System vs. Cottrell System Collection.* After the sonic collection work was completed, a Pangborn leaf-type bag filter with asbestos bags was installed on the furnace black pilot plant used for the sonic tests. This bag filter was used on a large number of subsequent runs to measure the efficiency of the Cottrell-cyclone system when making blacks of the same type as used for the sonic agglomeration study. The bag filter gave substantially complete collection of

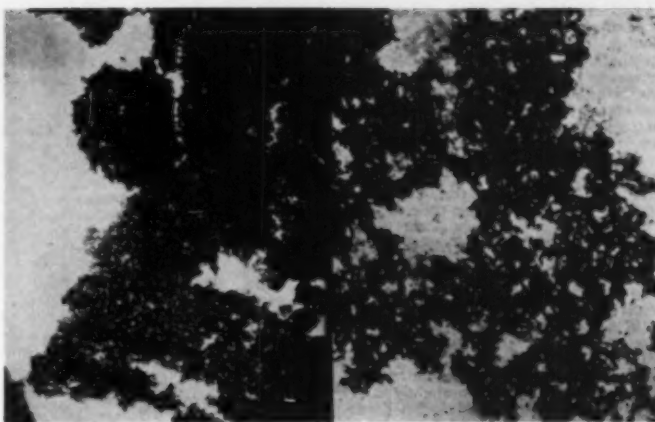


Fig. 15. Fine Furnace Black, Primary Particle Size .04-.05 $\mu$ . Photomicrograph (X100) of Agglomerates. Left-hand Panel Before Sonic Agglomeration; Right-hand Panel After Sonic Agglomeration.

the carbon in the exhaust from the secondary cyclone. Figure 16 shows the collection efficiency data so obtained. The flow rates used in the subsequent runs with the bag filter were in the range of 1000 to 2000 cu.ft./min. at flow conditions, which overlap the range of the sonic experiments. It may be explained at this point that in practically all runs represented in Figure 16, the inlet grain loading is lower the lower the particle size of the carbon black. Those points that lie more than about 10% below or above the curve for the most part represent cases in which (1) the grain loading is abnormally low or high because of leak conditions, or (2) the flow rate is

abnormally high (above 2000 cu.ft./min.) or low (below 1000 cu.ft./min.).

At the lower and upper limits of the particle-size range covered in the sonic experiments, the Cottrell-cyclone system showed collection efficiencies of 60 to 80% and 70 to 90% respectively, while the sonic experiments covered an efficiency range of 52 to 83%. No direct comparisons could be made between the sonic system and Cottrell systems as the only factor that could be held constant in operating the two systems was the use of the same cyclones for collecting agglomerates. However, it is fair to say that the sonic system showed efficiencies in the same range as the Cottrell

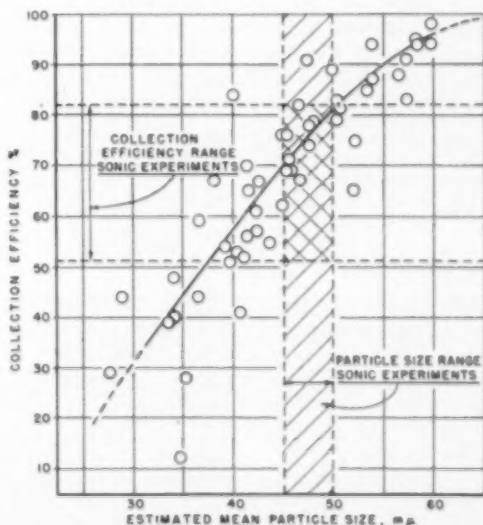


Fig. 16. Collection Characteristics for 3500 cu.ft./min. Pilot Plant Cottrell-cyclone System.



system when both were operated over the same ranges of flow, particle size, and grain loading. The range of collection efficiencies for the sonic system lies somewhat lower because of the excessive dilution from rotor gas. Most of the sonic runs were in the lower grain-loading range (1½ to 2½ gr./cu.ft.) and higher flow ranges (2000 cu.ft./min.) while most of the Cottrell runs were in the higher (2½ or greater) grain-loading and lower (1000 cu.ft./min.) flow range. It is concluded that, within the limits of the data, the sonic collection system gave performance equivalent to that of the Cottrell system.

**Comparison of Unagglomerated and Agglomerated Smoke from Sonic and Cottrell Agglomerators.** Figure 15 shows a fine particle-size furnace black at 100 X before (right) and after (left) passing through the sound field. The change in state of agglomeration is striking. Figure 3c shows the same comparison for a slightly larger particle-size furnace black before and after passing through a commercial (50,000 cu. ft./min.) Cottrell. It happens that this commercial grade of black (fine furnace black, Sterling 99, mean particle size about 45 mμ) is particularly hard to collect in the conventional Cottrell-cyclone system. The photomicrograph suggests that this is partly because of poor agglomeration. Figures 3a and b show the greater degree of agglomeration that is obtained with the Cottrell on still coarser grades of furnace black (about 70 mμ and 55mμ mean diameter respectively).

**Commercial Implications.** Sonic collection of furnace carbon black could be employed at any time with full assurance of collection efficiencies as good as with electrostatic agglomeration systems. The sonic apparatus is simple and dependable. In this respect it is similar to a high-speed pump or turbine. The only question yet to be answered is the total operating cost and first cost for a given case. Further experimental data and correlations are required to put sonic collection on a firm design basis.

### Acknowledgments

Grateful appreciation is herein expressed to the many contributors and collaborators without whose help this paper could not have been prepared for publication. They are: W. L. Loving, N. D. Steele, Mary Martin, Harold Danzer, Ernest P. Neumann, Caperton B. Horsley, Dr. H. W. St. Clair and Corinne Egan.

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### Discussion

**L. J. Ronayne** (Phillips Chemical Co., Borger, Tex.): Is there any physiological damage inherent in ultrasonic work?

**C. A. Stokes:** I don't think there is any question but that you will have some complaints from neurotic people because of the high-pitched scream of the sirens. That could be minimized to a point where it certainly wouldn't bother many people. As far as any actual damage is concerned, it is

utterly ridiculous that there would be any. At Wright Field, the Ultrasonic Corp. has supplied sound generators for testing the effect of the sound on human beings and, from what I hear of their work, the human ear can stand an amazing amount of punishment, so I would say that you would have to be conscious of the need for good personnel work; but other than that, it is perfectly all right.

**L. J. Ronayne:** The gas that you were using to drive the generator turbine was vented into the off-gas stream. Could you take reactor gas, pass it through your expansion turbine and then burn it in your furnace?

**C. A. Stokes:** The turbine that drives the generator consumes only a small amount of gas. In future installations, that drive mechanism will be in the nature of a speed control or a brake rather than a drive. You can readily appreciate that a siren will drive itself if the ports are shaped correctly, so that in new commercial installations, they can put a high-speed, variable-speed electric motor on there to regulate the speed of the rotor so that they can tune the chamber with the rotor very carefully. At present, it is absolutely necessary to dilute the gas in the system with the rotor gas. There is no way around that and it is important on small-scale installations but relatively unimportant on large-scale installations.

**L. J. Ronayne:** In the pelleting of loose black, does sonic agglomeration have any particular future as far as aiding that operation?

**C. A. Stokes:** I don't really think it does, at least not in the present state of the art.

**C. O. McKinney** (Standard Oil Co. of Indiana, Whiting, Ind.): What is the upper temperature limit for efficient sonic agglomeration?

**C. A. Stokes:** It probably is very high. There is no reason why the efficiency of agglomeration, if you can use that term, should not be as good at high temperatures as at low except that, of course, in a given smoke, the higher the temperature, the farther apart are the particles. At the same time, at the higher temperature, the smaller particles are pushed around more by Brownian motion and I see no reason why your agglomeration shouldn't be good at 1,000 or 1,500° F. You are probably thinking of a cat-cracker effluent. I think it would work all right. You might find there that those particles just don't tend to stick as well as carbon; some materials tend to stick together better than others.

(Presented at Eleventh Regional Meeting, Tulsa, Okla.)

# MINNEAPOLIS MEETING TO FEATURE MANAGEMENT, QUANTITATIVE ECONOMICS AND FREEZE DRYING

WILLIAM M. PODAS

Economics Laboratory, Inc., St. Paul, Minnesota

CHEMICAL engineers and guests from all over the country will find an outstanding technical program at the Minneapolis Regional Meeting of the American Institute of Chemical Engineers to be held at the Radisson Hotel Sept. 10-13, 1950. The program arranged by Chairman Edgar L. Piret (University of Minnesota) and Assistant Chairman Donald R. Guthrie (Minnesota Mining and Manufacturing Co.) will have both general and specific interest. The six scheduled symposia and the general Technical Program will appeal to chemical engineers in all branches of the profession. Some of the symposia, especially those dealing with Management and Quantitative Economics, will attract not only chemical engineers but other people connected with the chemical industry.

The six symposia and their chairmen were listed in the July issue.

## Symposia

*What Should You Know About Management?* The purpose is to present in a preliminary manner the various phases of management, a knowledge of which should be helpful to all chemical engineers. This is particularly true of chemical engineers looking toward a future in the realm of management. It will be pointed out in the discussions that chemical engineering provides an excellent background for an executive career. To add further interest it is planned to offer a quiz which will indicate to the individual just how much knowledge he has of management problems. The symposium will consist of a morning and afternoon session with three speakers in each session followed by a discussion period during which the speakers will act as a board of experts to answer questions.

The first subject is "What Is Good Organization?" with the speaker still to be named. The question "Are You of Executive Caliber?" will be discussed by Chaplin Tyler of the development department, Du Pont Co. Ernest B. Dale of the Graduate School of Business, Columbia University, will speak on the subject "Executive Development." G. Charter Harrison of G. Charter Harrison Associates, Madison, Wis., and an expert on practical accounting, will discuss the subject "The Chemical Engineer Meets the Accountant." Dr. William R. Spiegel, dean of the College of Business Administration, University of Texas, will answer the question "Why Industrial Relations?" Industrial relations or personnel management includes any activity whose major challenge is dealing with people as contrasted to dealing with material things. Dean Spiegel will show how real personnel

New Chemical Engineering Building, University of Minnesota.



New Solvent Extraction Plant, Minnesota Linseed Oil Co.



# SYMPOSIA AND TECHNICAL PROGRAM CHAIRMEN



W. L. Faith



R. H. Wilhelm



E. L. Piret



L. P. Scoville

management will ever remain personal. Stanley P. Farwell, president, Business Research Corp., Chicago, Ill., who has done much work in comparative salary surveys in determination of wage and salary rates, will speak on the subject "How Is Your Salary Determined?" An apt question even for chemical engineers.

**Phase Equilibria.** This is a continuation of the symposium initiated at the Houston Regional Meeting. The symposium will consist of a morning and an afternoon session and will include eight papers.

Papers will deal with phase equilibria in various systems: fluorocarbons, nitrogen - ammonia, acetone - methanol-water,  $\text{SO}_2$ - $\text{H}_2\text{O}$ . Other papers will deal with graphical techniques for reciprocal salt pair systems, salt effect in vapor-liquid equilibria, effect of addition of inorganic salts on solvent extraction from aqueous solution, and equilibrium conditions for flash vaporization of petroleum fractions.

**Applied Reaction Kinetics.** This symposium will consist of two morning sessions and one afternoon session and will include a total of 14 papers. Dr. Wilhelm will act as chairman of two of the sessions and Olaf A. Hougen (University of Wisconsin) will preside at the third session. This symposium deals with the heart of the chemical plant—the reactor. Streams of chemicals enter the reactor and product streams leave. Most of the equipment of the plant is concerned with reactant preparation and separation of the product into usable components but the reactor, which may be small physically by comparison, is the key unit. The symposium deals with problems and procedures in trying to obtain the most efficient design of such reactors.

Workers from universities (Columbia, Illinois, Minnesota, Pennsylvania, Princeton, Purdue, Wisconsin), indus-

try (Du Pont, Merck) and the Bureau of Mines will present papers. Some papers will deal with fundamental reactor considerations while others will deal with reactors for specific products such as chlorobenzene sulfonic acid, phosgene, ammonia, and oil from coal.

**Quantitative Economics in Estimation of Risk Factors in Capital Ventures.** Dr. Souders, who won the 1949 Professional Progress Award for Chemical Engineering at the Pittsburgh Annual Meeting, will present an informative program. The purpose of the symposium is to illustrate the application of quantitative economic data to the estimation of some of the risk factors which must be assessed in arriving at a decision on a proposed capital investment. Four topics will be presented in one morning session after which the meeting will be opened to general discussion.

Dr. Souders will cover the subject, "Population the Base of the Economy." This will be followed by an address entitled "Stoichiometry of Money" by Arthur B. Upgren, department of economics, University of Minnesota. Raymond H. Ewell, Chemical Economics Service, Stanford Research Institute, will speak on "Trends and Cycles in Chemical Industry." Dr. Souders will present the final topic "Weighing the Overall Risk in Process Ventures."

**Indoor Versus Outdoor Chemical Plant Construction.** This symposium will consist of one morning session and will include four papers which will attract a lot of interest as the speakers have all had practical experience on this timely and important problem. They will present advantages costwise and performancewise for outdoor construction of certain types of chemical plants. William H. Williams (Dow Chemical Co.) will discuss weather considerations in relation to plant construction. Workers from Du Pont Co. will discuss how

they arrived at the decision to build outdoor acetic acid recovery units. Homer Kieweg (Commercial Solvents Corp.) will discuss the plant safety problem in outdoor construction. J. R. Minevitch and G. B. Knight of the E. B. Badger & Sons Co. will present comparative costs on indoor versus outdoor construction.

**Chemical Engineering in Food Industries.** This symposium is appropriately presented at Minneapolis since this city is so closely connected with food processing and applications of chemical engineering in the food field. The symposium will consist of one morning session and will include three papers. V. C. Praschan (Clinton Foods, Inc.) will present a paper on "Chemical Engineering in the Frozen Food Industry." Developments in this industry have centered around evaporators and methods of freezing; seven types of evaporators now in use will be described and a similar discussion will be presented on seven different methods of freezing. Warren H. Goss (Pillsbury Mills, Inc.) will discuss "Chemical Engineering in the Edible Oil Industry." Workers from Swift & Co. will present a paper on "Chemical Engineering in the Meat Packing Industry." Unit operations in the manufacture of glue, gelatin, soap, feeds, fat derivatives, etc., will be described.

## General Technical Program

In addition there is a General Technical Program consisting of eight papers.

This program will consist of two afternoon sessions; at one, Edgar L. Piret (University of Minnesota) will preside and at the other Robert C. Ernst (University of Louisville) will preside. Four papers will be presented at each session.

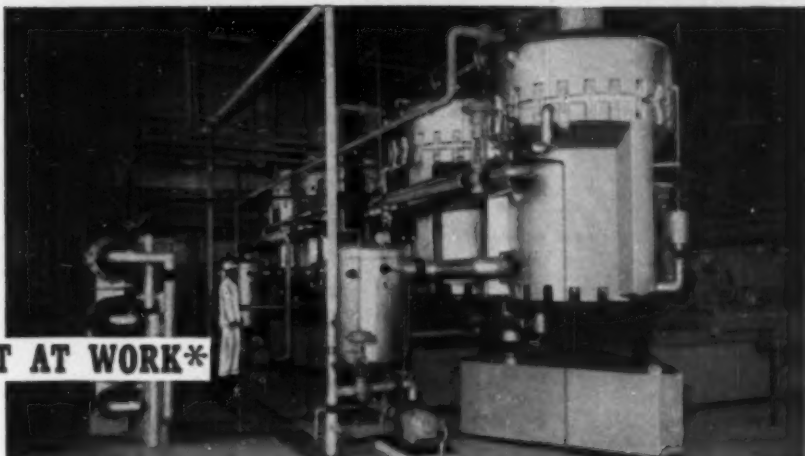
The speakers will cover the following subjects: "Freeze Drying with Radiant Energy"; "The Application of Diffusion Equations to Drying Schedules"; "Some Engineering Properties of Fully Fluorinated Compounds"; "The Sweep Diffusion Gas Separation Process"; "Continuous Ion Exchange"; "Continuous Multistage Ion Exchange"; "Biological Treatment of Kraft Mill Wastes"; "Measurement of Particle Size Distribution with the Light-Beam Sedimentation Balance."

## Plant Trips

Chairman Robert W. Callaghan (General Mills, Inc.) and his committee have arranged a schedule of interesting plant trips for visiting chemical engineers. These plants and laboratories will illustrate applications of chemical engineering in Minnesota. The schedule includes:

(Continued on page 11)


## LATENT HEAT AT WORK\*




Cleaver-Brooks Compression Stills at Arrowhead & Puritas Waters, Inc., Los Angeles, Calif. This plant is one of the largest compression still installations in the U. S., producing over 100,000 gallons of pure water daily.

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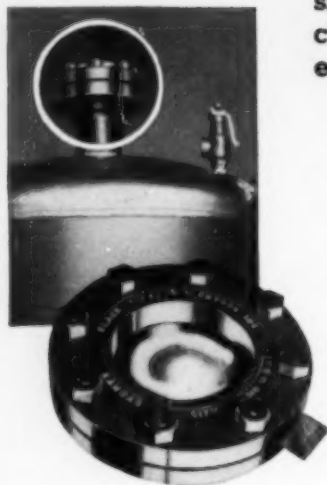
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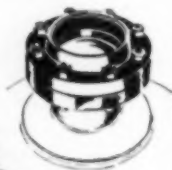
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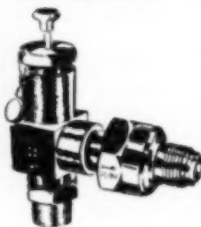
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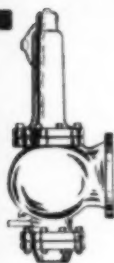
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## MINNEAPOLIS MEETING

(Continued from page 8)

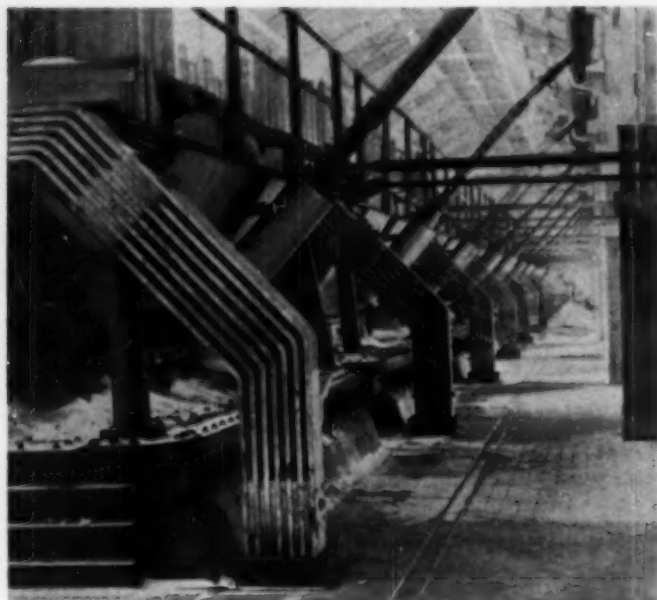
1. Minnesota Linseed Oil Co. (Minneapolis)—Trip will include both the new solvent extraction plant and the paint factory.
2. Ford Motor Co. (St. Paul)—A special point of interest is the glass furnace. Sand is mined right underneath the plant and converted into wind-shields for Ford cars.
3. New Chemical Engineering Building, University of Minnesota (Minneapolis)—This modern building will be completed and ready to receive students by September.
4. Hydraulics Laboratory, University of Minnesota (Minneapolis)—This internationally noted laboratory is located at St. Anthony Falls on the Mississippi River.
5. Swift & Co. (South St. Paul)—This is the largest meat-packing plant in the Northwest.
6. Theo. Hamm Brewing Co. (St. Paul)—Hamm's has just completed a large expansion and is now one of the most modern breweries in the country.
7. Minneapolis-Honeywell Regulator Co. (Minneapolis)—One of the country's largest manufacturers of thermal controls, regulators, etc.
8. Northern States Power Co., Riverside Plant (Minneapolis)—The largest steam generating plant in the Northern States system.
9. Land O' Lakes Creameries, Inc. (Minneapolis)—One of the original and now the largest farmers cooperative in the country. Visitors will see processing of butter and cheese and view the laboratories.
10. General Mills Inc. (Minneapolis)—Visitors will see one of the largest flour mills in this center of the milling industry.

### Ladies' Program

An attractive ladies' program has been organized by a committee headed by Margaret Hilligan (General Mills, Inc.) On Monday guests will attend a "vacation breakfast" and hear a short talk by Mrs. J. E. Oren, a well-known Twin City author and book reviewer. In the afternoon there will be a visit to the Betty Crocker Test Kitchen at General Mills, Inc., Minneapolis. Tuesday will feature an afternoon at Dayton's, one of the Northwest's finest department stores. The program will include lunch at the Skyroom and informal talks by fashion and homefurnishing experts and a tour through the store. On Wednesday there will be a luncheon at the Sibley Tea Room overlooking the beautiful Minnesota River where it meets the Mississippi. The Sibley House, which has been restored, is the oldest house in the State of Minnesota. The program will include a trip around the Sibley House followed by a trip around the Minneapolis lake and residential districts.

Visitors are encouraged to "see the sights" on their own. The hospitality committee will be on hand to guide you.

## CHEAP POWER FROM NATURAL GAS BRINGS ALUMINUM PLANT TO TEXAS



Interior of one of three pot rooms, showing the aluminum reduction cells and power buses supplying current.

Of the raw materials necessary for the economical production of aluminum, low-cost electric energy is most fundamental. Hydroelectric installations, in most cases, have solved the aluminum industry's need for the tremendous quantities of power required. Now the Aluminum Co. of America will obtain its electric energy from natural gas at its new Point Comfort reduction works near Port Lavaca, Tex. This plant, when in full production, will tap daily 30,000,000 cu ft. of natural gas for the generation of 120,000 kw. of electric power and the production of 300,000 lb./day of aluminum ingot.

The plant is situated on a 3,000-acre tract on Matagorda Bay and consists of power-generating facilities, aluminum reduction cells, and a carbon plant for

electrode paste preparation. The plant is made up of three pot lines, as a series of reduction cells is termed, each with its own power unit. A power unit contains forty 1600 hp. gas engines, each of which drives a 1000-kw. d.c. generator and a 125-kva. a.c. generator. The gas engines are radial in design with eleven cylinders of 14-in. bore and a 16-in. stroke. The engines are mounted horizontally at the first floor level and are directly connected to the generators on the basement floor right beneath. The engines are water cooled and heat is removed from the cooling water in finned aluminum heat exchangers equipped with an 84-in. diameter fan driven by a 25 hp. motor. Exhaust gases from each engine pass to the atmosphere through a 7.5 by 50 ft. aluminum stack.

### OFFICERS OF S.C.I. NAMED

Officers of the American Section, Society of Chemical Industry for 1950-51 were recently announced by the executive committee. The new honorary chairman of the group is Gustavus J. Esselen, Esselen research division, U. S. Testing Co., Boston, Mass.; honorary vice-chairman, Robert C. Swain, American Cyanamid Co., New York; honorary secretary, Fred-

erick W. Adams, Spool Cotton Co., New York, and honorary treasurer, Walter J. Baeza, Industrial Research Co., New York.

Two new members were elected to the executive committee. They were J. L. Bennett, manager of chemical operations, Hercules Powder Co., Wilmington, Del., and Randolph T. Major, vice-president and scientific director, Merck & Co., Rahway, N. J.

## OIL SHALE REVIEWED IN OHIO STATE SERIES

"Review of the Estonian Oil Shale Industry. With a Brief Account of Oil Shale Development in the United States" by Peter O. Krumin is the title of Engineering Experiment Station Circular No. 50 of the Ohio State University Studies. The pamphlet contains some 125 pages of text, tabular matter, and line drawings. New data are included, such as High Temperature Carbonization of Oil Shale. Some 70-odd sources are cited in the bibliography.

The price of the circular is \$1.

The Engineering Experiment Station in close cooperation with the Geological Survey will continue to study the Ohio oil-shale resources and their possibilities for industrial utilization. The Station under a cooperative agreement with the Bureau of Mines is receiving oil shale and shale oil samples from the experimental plant in Rifle, Col. These samples are being used for basic research.

Peter O. Krumin, associate professor of fuel research, Engineering Experiment Station and department of chemical engineering, The Ohio State University, is an Active member of A.I.Ch.E.

## NAT. CONGRESS APPLIED MECHANICS, CHICAGO, 1951

The first U. S. National Congress of Applied Mechanics will be held June 11-16, 1951, at Chicago, Ill., under the sponsorship of U. S. National Committee on Theoretical and Applied Mechanics, American Institute of Chemical Engineers, and other technical societies and organizations interested in mechanics.

Abstracts of papers, which should constitute original research in Applied Mechanics, including kinematics, dynamics, vibrations, waves, mechanical properties and failures of materials, stress analysis, elasticity, plasticity, fluid mechanics and thermodynamics, are to be sent directly to the chairman of the editorial committee, Eli Sternberg, Illinois Institute of Technology, before April 14, 1951, and such presentation is subject to the full manuscript having been submitted prior to June 11, 1951. Papers should not exceed 5000 words.

General Chairman of the National Congress is L. H. Donnell of Illinois Institute of Technology and the representative for A.I.Ch.E. is Prof. Thomas B. Drew, department of chemical engineering, Columbia University, New York.

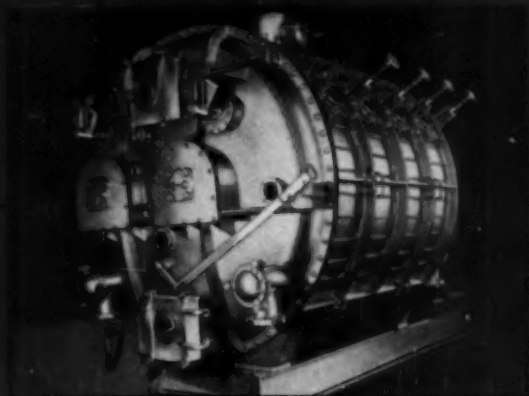
Inquiries regarding the Congress may be addressed to the Secretary of the Congress, N. M. Newmark, University of Illinois, Urbana, Ill.

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## NEW SODIUM AND CHLORINE PLANT OF NATIONAL DISTILLERS



National Distillers Chemical Corp. has begun commercial operations at its new \$10,000,000 plant in Ashtabula, Ohio. The corporation made its first commercial shipment of metallic sodium recently, and is also delivering chlorine to the adjacent plant of Hooker Detrez, Inc. The chemical corporation is a wholly owned subsidiary of National Distillers Products Corp.

## E. J. C. REPORTS ON NATION'S WATER POLICY

In a huge study on the nation's water policies, the Engineers Joint Council took a stand last month against "excessive and unsound" water resources practices which it attributed to competing federal agencies and Congressional "response to pressure and trading," and called for a halt in further authorizations until uniform national policy has been adopted.

In an extremely critical report an 80-man committee of Engineers Joint Council, representing the country's five major engineering societies, suggested specific remedies and warned "both political parties" that "public money is limited in availability." In presenting the report to President Truman and the Commission, the committee condemned "political expediency" tactics and "exaggeration of benefits claimed" and warned that unless the "degradation" of the last two decades in the "application of criteria to water resources development" is halted, "estimates of benefits will soon become mere excuses for justification, not valid reasons for construction of projects."

The A.I.Ch.E. is a member of Engineers Joint Council along with four other national engineering societies: American Society of Civil Engineers, American Institute of Mining & Metallurgical Engineers, The American Society of Mechanical Engineers, and American Institute of Electrical Engineers. R. D. Hoak of the Mellon Institute was the A.I.Ch.E. representative on the committee. The report is on sale by E.J.C., 20 West 39th St., N. Y. 17, for \$1.50. Other criticisms voiced in the report follow:

The public utility form of contract authorized by the Reclamation Projects Act of 1939 can be made workable and acceptable. It requires only that the Bureau of Reclamation shall recognize the obligations of public utility service and not use such contracts to implement social changes.

Of the billion-dollar Missouri Basin development, which the report asserted "was authorized by Congress in haste and without appropriate public hearings within the Basin," the report states:

From an engineering standpoint the planning and execution is almost entirely backward. Characteristics and needs were ignored in determining which agency would develop the water resources in a particular part of the Basin. Specific projects were proposed and approved without regard or consideration of their effects on the economy, transportation, local government of counties and general welfare of the people in the areas and adjacent regions of the reservoirs. Serious conflicts continue to exist in the jurisdiction of overlapping geographic projects. There is little wonder the people are unconvinced of the feasibility of navigation on the Missouri River. After expenditures of more than \$230,000,000 the navigation savings are less than \$4,000,000.

Although the report did not direct itself to the activities of any particular agency, it cited the fact that the Department of the Interior, Corps of Engineers, Department of Agriculture, Federal Power Commission, U. S. Public Health Service, Weather Bureau, Coast and Geodetic Survey "and many others" are concerned with one phase or another of water development.

To alleviate competition between agencies and to safeguard the public against exaggerated intangible benefits claims as well as improper allocation of costs between general taxpayers and project beneficiaries, the report recommended creation of a board for the impartial analysis and appraisal of all federal water projects. Such a board, the report pointed out, would also serve to protect the public against "the present excessive and economically unsound rate of planning and Congressional authorizing of developments," since the board's review and re-

port would be "prerequisite to the authorization or appropriation by Congress of or for projects of that kind."

In support of their proposal that engineers without continuing interest in the projects be utilized to determine economic justifiability of dams and reservoirs built for flood control, irrigation, navigation and power, and any combination of these services, the engineers pointed out that today's water developments have reached a level "representing billions of dollars annually instead of the millions per year of the period prior to 1930."

Other recommendations included:

Authorization of Federal water projects solely by Congress.

No further authorization until uniform national policy has been adopted.

So far as practicable, projects should be self-supporting.

Authorizations should serve as an absolute limit on appropriations, and should not be in blanket form.

The Congress should review any substantial change in project, and authorizations should become void if the project cost overruns by 20 per cent the cost estimated at time of authorization.

Adequate time should be allowed for collection of essential data and for determination of whether there is real need for a proposed development.

Expenditures should be at a lower rate during periods of general prosperity and at a greater rate during periods of reduced business activity and employment.

No engineers now actively engaged under the federal services served on the engineers' committee, the report stated, but experience within the federal services is well represented, about one third of the membership at some time having had actual experience there. The report will be expanded at a later date "to cover matters not possible of inclusion under the original effort and to provide further documentation."

## ZINC OXIDE

### DATA AVAILABLE

For the user of zinc oxide, the St. Joseph Lead Co., 250 Park Avenue, N. Y. 17, N. Y., has a new 60-page pamphlet on this pigment. The book is divided into two parts, the first concerning itself with production of lead-free zinc oxides, and covers the mining, milling and smelting, etc. The second part details the physical properties of zinc oxide including general properties, use in rubber compounding, in protective coatings, in the pharmaceutical, chemical, ceramic fields, etc.

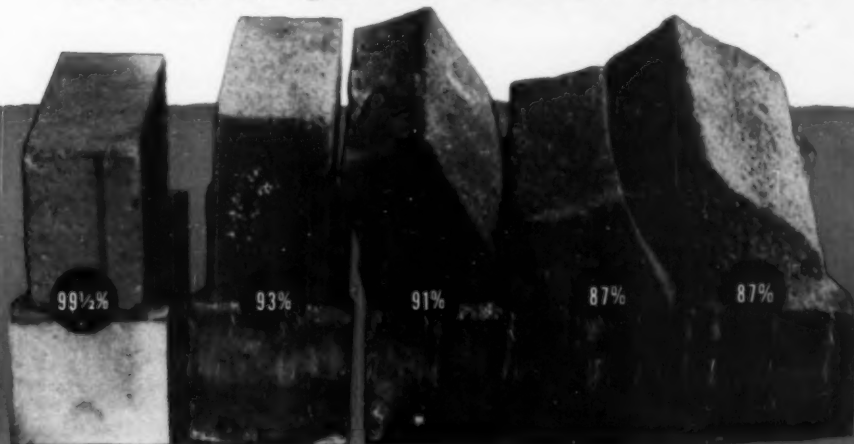
Copies are available free of charge to technologists and members of purchasing departments if the request is made on company letterhead.

(More News on page 16)

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(Photo and data: Courtesy of Richard C. Ramsey Son Co.)

ALCOA Alumina increases stability and high-temperature resistance of refractories. This is clearly shown in the specimens illustrated above. All are alumina-content brick, and all were held at a temperature of 3400° F. (Cone 40, flat) for four hours. From left to right, the alumina content of each brick is: 99½%, 93%, 91%, 87% and 87%. You can see what a "whale of a difference" a little extra ALCOA Alumina makes. (As temperatures and alumina content are decreased, similar results are obtained.)

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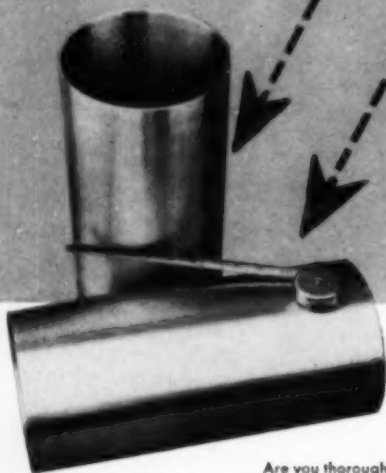


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## ENGINEERING REGISTRATION IN LOUISIANA

Information about a new, recently passed law in Louisiana has been received from Henry J. Molaison, secretary of the New Orleans Section, and J. W. Weiss, Chairman of the A.I.Ch.E. Committee on Professional Legislation. Essential points in the new law affecting chemical engineers are as follows:

Certificates of registration will be issued in one or more of the following branches of engineering: agricultural, chemical, civil, electrical, mechanical, metallurgical, mining, petroleum. (Act also registers land surveyors.) Certificates of registration will mention branch of engineering.

Minimum qualifications for registration: (a) Graduation from an approved engineering curriculum, or (b) Eight years of satisfactory engineering experience and examination, or (c) Long-established practice—20 years, including 12 in responsible charge.

The Act also includes a one-year "grandfather clause" for all branches of engineering except civil engineering.

Effective date for the new law was July 26, 1950.

The State Board of Registration for Professional Engineers and Land Surveyors, created by the new law, will consist of seven professional engineers to be appointed by the Governor, from a list of nominees submitted by the Louisiana Engineering Society. The law provides for a minimum of three members of the new board to be retained from the old "State Board of Engineering Examiners" who administered the old Civil Engineer's Law. These three will be civil engineers, and the Louisiana Engineering Society is presently in the process of preparing a list of nominees from among the other engineering branches.

Except for those engineers dealing directly with the public, the registration is permissive rather than compulsory.

**MATHIESON CONTRACT  
TO BLAW-KNOX CO.**

Chemical plants division of Blaw-Knox Co. has been awarded a contract by Mathieson Hydrocarbon Chemical Corp., Baltimore, Md., for the engineering and procurement of a large new chlorine and caustic soda plant to be located at Saltville, Va.

Expected to go into operation in 1951, this new chlorine production unit will be based on the Mathieson mercury cell process, which produces chlorine and rayon grade caustic soda of 50 per cent concentration directly from the cells.

Blaw-Knox has been authorized by Mathieson to build chlorine and caustic soda plants using the Mathieson mercury cell technique and licenses.

## PETROLEUM FELLOWSHIP FOR UNIV. OKLAHOMA

The Maloney-Crawford Tank and Manufacturing Co., in Tulsa, Okla., has established a graduate fellowship in the school of chemical engineering at the University of Oklahoma which will start in September, 1950. The purpose of the fellowship is to promote fundamental research which will be of interest to the petroleum industry. The fellowship is open to chemical engineering students who have already completed one year of graduate study.

## EXTEMPORANEOUSLY OR—

If it is conceded to be at least a half-truth that engineers are proverbially bad speakers then even a cursory reading of a new pocket-size manual entitled, "Speaking Can Be Easy . . . for Engineers, Too," should completely explode that idea.

Prepared by the committee on relations with industry of the A. S. E. E. this manual is addressed primarily to the engineer. It can be read in a half hour including quick glances at the illustrations which in a humorous vein emphasize the major points. The pamphlet contains 24 pages and is distributed by Engineers' Council for Professional Development at 50 cents with a 25% discount for lots of 100.

In the "speaker" section the subjects covered include: What Type of Speech?, Attention Patterns, and Platform Manners.

The meeting section is of special interest to the chairman of a meeting. It treats of effective introductions, starting and handling questions, etc.

## CHEM. ENG. PROJECT BY A.E.C. AT IOWA

A research project in chemical engineering has been established by the Atomic Energy Commission at the State University of Iowa. The project involves an investigation of the separation of gases by diffusion through permeable membranes. The work will be carried out under the direction of Prof. Karl Kammermeyer of the division of chemical engineering.

## KINETIC MERGED WITH DU PONT ORGANIC

Operations of Kinetic Chemicals, Inc., long a Du Pont Co. affiliate, and wholly owned by the Du Pont Co., since December, 1949, was integrated with those of the company's organic chemicals department July 1. A new Kinetic chemicals division will be set up to handle sales of Kinetic products, the Freon fluorinated hydrocarbons used principally as refrigerants and aerosol propellants.

(More News on page 25)

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# MARGINAL NOTES

*Marginal Notes* is devoted this month to one book, *Unit Operations*, by G. G. Brown and associates, to be published later this month. It is reviewed by two prominent chemical engineers, W. L. Faith, director of engineering, chemical division of Corn Products Refining Co., Argo, Ill., formerly a professor of chemical engineering; and C. C. Monrad, professor and head of the department of chemical engineering at Carnegie Institute of Technology, Pittsburgh, Pa., who went to the teaching profession after years of industrial experience. Dr. Faith reviewed the first part of the book, and Professor Monrad the second part. Both, however, viewed it overall, and this evaluation is given before their technical appraisal.

*Unit Operations*. G. G. Brown, A. S. Foust, D. L. Katz, R. Schneidewind, R. R. White, W. P. Wood, J. T. Banchemo, G. M. Brown, L. E. Brownell, J. J. Martin, G. B. Williams, J. L. York. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y. (1950) 612 pp., 8½ x 11, double column. \$7.50.

## General Comments by C. C. Monrad

PROF. G. G. BROWN and the chemical engineering staff at Michigan have prepared the first undergraduate textbook in the field of unit operations since the revisions of the well-known books by Badger and McCabe, and Walker, Lewis, McAdams and Gilliland in 1937. Significantly, perhaps, this is also the first book using the title "Unit Operations" and the first in which the individual unit operations are not discussed as separate and independent fields.

Dr. Brown and his associates have approached the subject of unit operations in a somewhat novel manner. This approach differs from those in earlier books somewhat as follows:

- The sequence is roughly in the order of increasing difficulty.
- The main groupings in the book are (I) Solids, (II) Fluids, (III) Separation by Mass Transfer, the Ideal Stage Concept and (IV) Energy and Mass Transfer Rates.
- Within these groups methods are developed for handling similar situations in different unit operations, particularly in Parts III and IV.
- The thermodynamic approach is used more generally than is common in the present textbooks.

As a consequence of this procedure, no clear demarcation is made between the individual unit operations, particularly those concerned with mass transfer. Distillation, for example, is treated in several places under different subjects and is really considered as one of the many applications of fluid-fluid contacting. The conventional method of teaching fluid flow, heat transfer and the separate mass transfer operations could be continued only with difficulty if this book is used as a text.

The procedure used by Dr. Brown and his associates brings with it several advantages, however. One general devel-

opment of a method of analysis or design suffices for several unit operations, such as distillation, absorption and extraction; a consistent nomenclature can be maintained, and the similarities of the various fluid contacting operations are made more clearly apparent. Time and space are thus released for a more extensive coverage of the various unit operations than has been possible in previous books in this field. Enough material has been included to require about three semesters of work to complete. In fact much of the material is suitable for graduate instruction. The book is amply illustrated with 568 drawings, photographs and other illustrations of satisfactory size for easy use.

With such a large staff of coauthors some differences in writing techniques would be expected, but this is not noticeable. Generally, the book is written in simple language, readily understandable sentence by sentence, but at times it seems a little monotonous and lacks some emphasis and clarity. Much care is given to developments of theoretical mathematical equations and design methods but these are sometimes based on incomplete or fuzzy discussions of the underlying principles.

The incompleteness of some discussions may be illustrated by the definitions of the various types of heat transfer and in the development of analogies. Conduction is defined as the transfer of heat from one part of a body to another, or between two bodies in physical contact without significant displacement of the particles of the body. Hence heat flow through a viscously moving film in a wetted wall column is not conduction by this definition, and neither is it convection by the definition set forth by the authors. In the subject of analogies a discussion is given of the Prandtl mixing length but it is difficult to see how a student could follow the development, as many of the assumptions are omitted. From this it is shown that a point Reynolds number can be developed based on local velocities and local mixing lengths and this is shown to be the ratio of momentum transfer by turbulent action to that by molecular action. It is then broadly implied that the usual Reynolds number based on average velocity and

tube diameter represents the same ratio for the whole tube. Partial derivations of this type are somewhat prevalent throughout the book and detract from its usefulness in clear presentation of fundamentals since considerable amplification must be given by the instructor or reference made to other sources.

Many teachers will wonder if this book is usable in the absence of previous training in chemical engineering thermodynamics. The authors state that their treatment presupposes a course in material and energy balance or one in thermodynamics. There appear to be only a few subjects which would require amplification by the instructor if the student is deficient in thermodynamic training.

It is probable that this book will excite considerable differences of opinion regarding its value for a beginning course in the unit operations. The organization of the material will be approved by some and not by others. Its coverage in terms of both descriptive matter and development of methods for design is considerably more complete and up to date than any other single book in the field. Its drawbacks, perhaps, are in rather sketchy developments of some of the simpler basic principles and definitions and inadequate discussion of the limitations of some of the procedures suggested.

As the authors imply, the book is suitable for courses of various types by suitable deletion of material, and if desired by rearrangement of the topics in sequence. Students and professional chemical engineers will find it a distinctly useful addition to their library in this field.

## General Comments by W. L. Faith

Professor Brown and his colleagues have brought a novel, yet modern, approach to the study of the unit operations. Not only is the approach modern but everything about the book is new. It is a big book of nearly 600 pages printed in double columns for ease of reading. Even the title "Unit Operations" is indicative of the down-to-earth approach of the authors. One wonders

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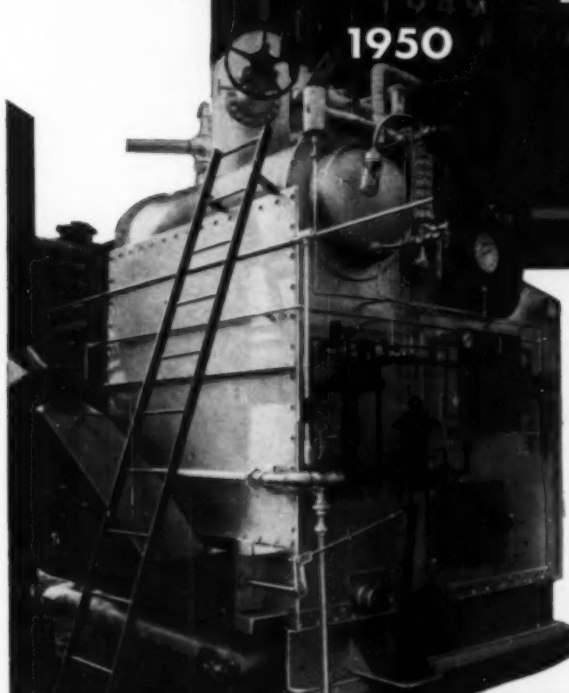
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why this title has not been used previously. The writer predicts that the book will be widely adopted as a textbook and as a "desk-top" reference for practicing engineers.

**Comments on Parts I and II  
by W. L. Faith**

The first chapter, Introduction to the Unit Operations, sets the stage or tempo for the entire work. Here the student is given the plan of the book with the unit operations which treat solids alone coming first (Part I), followed by those involving fluids (Part II). In this latter group are treated those unit operations where a fluid boundary phase is involved "whether the solid particles are flowing through the fluid as in classification and flotation, or whether the fluid is flowing through a solid as in fluid transportation or filtration." This is so natural and logical a classification that one wonders why the approach has not been more widely used. Part III covers separation by mass transfer; Part IV takes up those operations involving energy and mass transfer rates. In this manner the subject is introduced to the student through the comparatively simple treatment of solids, followed by increasingly difficult subjects which, in turn, lead to the complex unit operations involving the rates of energy and mass transfer.

One of the points stressed in the introduction is the practicality of the unit operations. The student learns that the unit-operation concept is a method for classifying and formulating engineering experience, first by single observations, then many observations empirically correlated and extrapolated, until equations representing the plotted data can be "rationalized or 'derived'." The student is cautioned, however, "that the practical operator in the plant who may never have seen the equation or heard the term 'unit operation' has probably made more observations himself than all those involved in deriving the equation." Consequently, in the chapters that follow, the authors have no hesitancy in using empirical methods where they best serve the purpose. Nevertheless, this is not a cookbook; the theory of the various unit operations is rigorously presented.

Finally, in the brief introductory chapter, the four fundamental concepts which form the basis for the calculation of the various operations are described. These are the Material Balance, the Energy Balance, the Ideal Contact (contact of phases or materials under such conditions that equilibrium is obtained), and Rates of an Operation. In the succeeding chapters, the underlying concept of the particular operation is emphasized until search for the applicable concept becomes almost second nature.

It is interesting to note that in this introductory chapter the authors make no pretense of tying the unit operations to chemical engineering. One not cognizant with the various branches of engineering would assume the book was meant for all engineering students of the process industries, e.g., chemical, mechanical, and metallurgical, as indeed it is and should be.

From a quantitative standpoint the first part of the book, five chapters concerning solids, is probably the weakest not by fault of the authors but rather because of the state of the art. On the other hand, the descriptive material is well presented and excellently illustrated with photographs and line drawings supplied by manufacturers.

Chapter two on properties of solids serves largely as an introduction to the subject. A great deal of chapter three on screening is devoted to methods of making and reporting screen analyses, together with the significance and evaluation of the analyses. Chapter four on size reduction presents excellent descriptive material and illustrations on the usual pieces of size reduction equipment ranging from jaw crushers to ball mills. A few common types of mills, e.g., hammer mills, are not mentioned. The discussion of operating variables of the different types of units is especially noteworthy. Useful manufacturers' data on capacities and energy requirements of various units are tabulated. At the end of the chapter there is an unusually complete list of problems. Each chapter in the book, in fact, is followed by a list of problems, all of which are new to the writer and well conceived. Unfortunately, several chapters have fewer than three problems. The handling of solids, including material on industrial trucks and cranes, is covered in chapter five much more thoroughly than is usual in a chemical engineering textbook. Major emphasis is on conveyors and considerable empirical data on commercial conveyors are presented. A discussion of weigh hoppers and scales is also included.

The second part of the book deals with fluids and is an exceptional addition to the chemical engineering literature. It is presented in 15 chapters of increasing complexity. A complete review of each chapter would require more space than is available, so it is hoped that isolated comments which occurred to the writer as he read through Part II will be helpful to those desiring to know the scope of the treatment.

In the introductory chapter on properties of fluids, the authors discuss viscosity, Reynolds number, and relative motion between fluids and solids. Detailed consideration is given in chapter

seven on Flow of Solids Through Fluids to maximum velocity, types of flow, friction factor charts, hindered and free settling, and mathematical analyses of two-dimensional motion. Chapter eight covers Classification and presents an excellent description of equipment including air classifiers, elutriators, a variety of wet classifiers, jigs, and tables, and a short section on electrostatic classification.

The subject of flotation is surprisingly well handled in chapter nine for a chemical engineering textbook. The calculations for a flotation process are illustrated by an example in which an unusual insight into flotation cell specification and operation is presented.

The discussion on fluid transportation begins with a consideration of the energy balance and the importance of consistent units. Based on this balance, the flow equation is derived and its various components discussed. In setting up the balance, the thermodynamic concepts learned by the student in elementary physical chemistry are brought in naturally and without fanfare, even without the awesome label of "Thermodynamics." There follows a study of dimensional analysis, friction factor charts, and the various dimensionless groups such as the Reynolds and Kármán numbers. Near the end of the chapter, special cases, such as Weymouth's Equation for Gases, pressure drop across tube banks, and the flow of compressible fluids at moderate velocities are analyzed. By this time the value and need of thermodynamic considerations in fluid flow problems has become obvious to the student. An excellent group of 19 problems is appended.

Following are chapters on Measurement and Flow of Fluids, and Pumping and Compressing. The latter, with descriptive material on the construction, operating features, and applications of a wide variety of pumps and compressors, is concise and well illustrated.

Chapter fifteen on Gas Flow at High Velocity shows the thermodynamic approach at its best. This chapter covers nozzles, adiabatic, isothermal, and non-isothermal flow in an excellently balanced treatment using both theoretical and empirical calculations.

Having considered the flow of solids through fluids and of fluids in pipes, the next logical subject is the flow of fluids through beds of solid particles. Development of the subject starts in chapter sixteen with the flow of a single fluid phase through beds of regularly shaped particles, randomly packed. The concepts of porosity and sphericity are fully explained and then utilized in a generalized illustrated example of the computations involved in the types of flow encountered in porous beds. The



next chapter considers flow of fluids through porous media—two fluid phases. Filtration, because it involves primarily the flow of fluids through porous media, is logically considered under that heading. The chapter is unusually well balanced for a treatise on filtration. The first half consists of an excellent presentation of the design, utility, and operation of various types of commercial filters; the last half treats filter calculations. The authors are to be commended for including calculations on the blower requirements of rotary filters. Unfortunately, the chapter contains no discussion of filter cloth, which could well have added to the value of the work. There is also indicated a widespread use of float traps to protect vacuum pumps, although usual industrial practice calls for an elevated foam trap and a barometric leg.

In the chapter on centrifugation, the section on equipment is both sound and comprehensive. The mathematical section is short but contains a few pertinent methods of calculation.

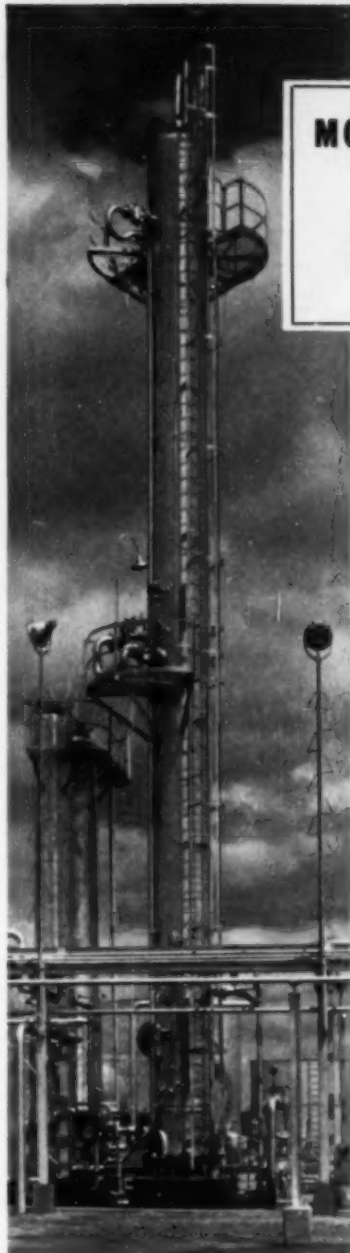
The final chapter in "Part II—Fluids" covers Fluidization of Solids, a field only recently subjected to engineering study. In fact, the chapter presented here is the first in any text or handbook that covers the basic engineering phases of the subject. The discussion includes particulate fluidization, aggregative fluidization, pressure-drop calculations, and the transportation of fluidized dispersed solids.

#### Comments on Parts III and IV

by C. C. Monrad

Part III covers separation by Mass Transfer, the Ideal Stage Concept; and Part IV, Energy and Mass Transfer Rates. These two parts embrace the various diffusional operations and heat transfer. The equilibrium stage concept is applied in Part III to various mass transfer operations where stage equipment is used commercially, such as distillation, absorption, extraction, adsorption and mixtures of these such as azeotropic and extractive distillation. Part IV is a development of heat transfer, evaporation, crystallization, agitation, and rates of mass transfer and the rate concept is applied to some of the operations previously studied by the stage concept.

Part III begins with solid-liquid extraction or leaching and general procedures are developed for calculating the stages required, using equilibrium relationships and material balances. This is then expanded to liquid-liquid extrac-



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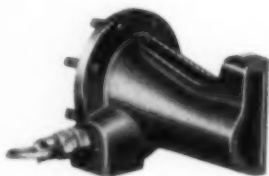
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tion, where equilibrium relationships are more difficult but the operation is still substantially at constant temperature. The development is carried then to distillation and absorption where vapor is contacted with liquid. Since these operations often involve temperature changes, energy relationships now become important and must be considered in addition to material balance and equilibrium. The procedure here is to develop the energy balance, derive the Ponchon-Savarit method for binary distillation, and then permit the simpler situations involving constant molal overflow and vaporization and constant relative volatility to drop out as special cases. The absorption-stripping factor procedure is developed for absorption and distillation and a short introduction is given to multicomponent, azeotropic, extractive, and batch distillation. General mechanical features of bubble-tray towers are discussed from the viewpoint of tray design, pressure drop, stability and control.

In Part IV heat transfer by conduction, convection and radiation is developed in rather a conventional fashion. Conduction is carried to simple cases of unsteady heat flow. Radiation to finite surfaces and from hot gases is discussed quite adequately for undergraduate instruction and follows the general procedure used by Hottel. The treatment of convection, although conventional in approach, is somewhat lacking in clarity and does not show the limitations of the various empirical equations suggested.

Evaporation is treated rather sketchily, emphasis being placed on a discussion of the various types of evaporators and on the use of the enthalpy-concentration chart for enthalpy and material balance calculations. Crystallization and agitation are also treated briefly but probably thoroughly enough for undergraduate training.

Mass transfer is prefaced by a short discussion of diffusion theory and then methods of design are developed based on coefficients of mass transfer and on the H.T.U. concept. In general fugacity is considered to be the driving force for mass transfer operations, but in all applications it is assumed that partial pressure or concentration differences will suffice. A short discussion of analogies between momentum, heat and mass transfer is also included here but with few applications. The development of mass transfer is rather cryptic and will require considerable amplification by the instructor or resort to other literature. The treatments of psychrometry and drying are short but probably adequate for undergraduate instruction.

LETTER TO THE EDITOR  
THAT "PROFESSIONAL"  
MAN AGAIN

Sir:

I would like to add to the discussion appearing in the June, 1950, issue relating to the professional status of chemical engineers. For some time now, the several national and local organizations representing chemists and chemical engineers have been sponsoring a drive to have the chemist and the chemical engineer recognized by others as "professional men." In my opinion, one of the distinguishing characteristics of a "professional man" has been neglected in the emphasis on technical skill, advance training, education for leadership, etc.

On the basis of what is being stressed for chemists and chemical engineers, there is little reason why a good garage mechanic, a good plumber, a good carpenter, or the like, should not enjoy the same rating.

The compelling reason for the drive for a professional status appears to be that we chemists and chemical engineers feel our work is so specialized, mysterious to others, and miraculous in its results as to warrant the appellation. On this ground, the term "professional" carries no higher meaning than when applied to the trades mentioned above as well as "professional" baseball players, wrestlers, singers, tennis players, golfers, etc.

The word "professional" has a different meaning, however, when applied to doctors and lawyers. Neither of these groups has actively campaigned for that status by publicizing the fact that it felt itself entitled to the rating. Both have a specialized training obtained after completion of college curricula. Both continue their education after graduation to keep up with changes and developments in their respective fields. Up to this point our objectives to the achievement of a professional status differ only in the subject matter. But, lawyers and doctors are bound by a strict and rigidly enforced code of professional ethics.

This code is self-imposed and self-enforced. It governs the doctor and the lawyer in their relations with clients or patients and with fellow doctors and lawyers. It is also designed to protect the public from improper action by those coming within its purview. Doctors and lawyers receive formal education in professional ethics, and most adhere strongly to the rules. Those that breach the code are soon found out and ignominiously barred from further practice.

In my opinion this is a major factor contributing to the honor and dignity of the legal and medical professions. If this is the type of professional status we desire, perhaps consideration should be

(Continued on page 25)



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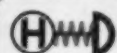
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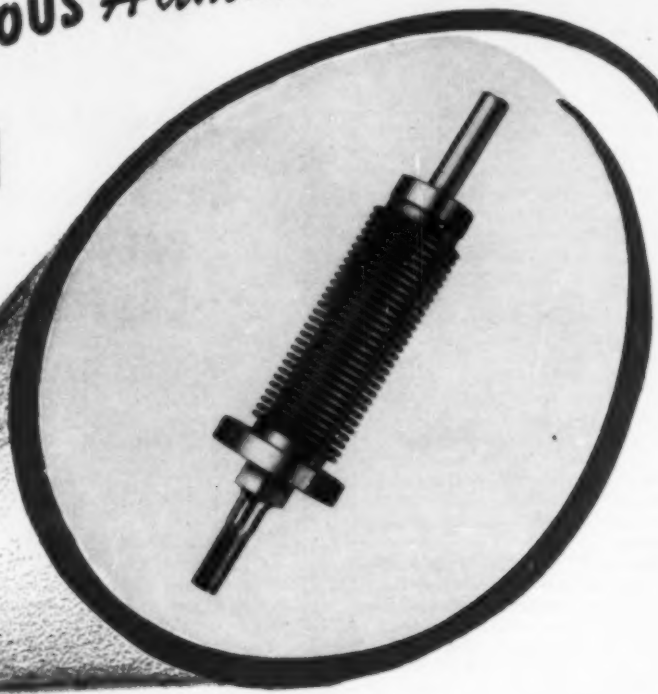
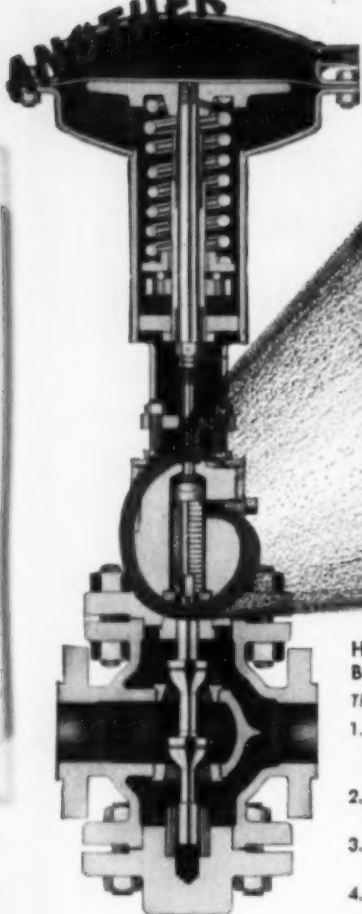
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**1 • IONIZATION GAUGE.** For the measurement of vacuum down to  $5 \times 10^{-10}$  mm. of mercury, Westinghouse Corp. has a new ionization gauge based on electronic principles. It resembles a triode vacuum tube with the filament, grid, and ion collector in reverse of the conventional arrangement. It can be run on standard power systems, and instruments with special tabulation for direct reading are available.

**2 • HYDRAULIC HAND PUMP.** For generating pressures manually, a two-stage portable force pump using two pistons is new with the Baker Oil Tools, Inc. Pressures up to 2500 lb./sq.in. can be developed with the low pressure pistons, and up to 6000 lb./sq.in. with the high pressure pistons. The pump is for various processing jobs around the plant; removing cores from core barrels, plungers from insert liners, and for testing valves, fittings, tubings, casings, etc.

**3 • STREAM SPLITTER.** For breaking up single streams of dry, free-flowing materials such as chemicals, plastics, flour, fertilizers, etc., the Richmond Manufacturing Co. is in production with a new stream splitter which can divide a single stream into two to eight separate and equal streams. Capacity adjustments may be made from the outside. The machine operates by having the material strike an impeller rotating at approximately 300 rev./min. The impeller agitates the material into a uniform cloud which settles into various outlets.

**4 • GATE VALVE.** A corrosion resistant flanged gate valve in sizes ranging from  $1\frac{1}{2}$  in. to 12 in. is new with the Pioneer Alloy Products Co. Primary service rating is for 150 lb./sq.in. at 500° F. Specially designed for petroleum refining, chemical processing, pulp and paper mills, the model is available

in 302, 304, and 316 stainless steel. Teflon packing is used.

**5 • HAMMER MILL.** New with The Bauer Bros. Co. is a hammer mill developed by them and a special research group at Ohio State University. Total power input from 55 to 90 h.p., 1750 rev./min. Has a direct-driven exhaustor, pressure feeder, remote control, magnetic separator. Screens may be changed without stopping the mill. Bulletin available.

**6 • PILOT PLANT KETTLE.** A new kettle for pilot plant and small batch use designed by the Chaffee Design and Manufacturing Co., features a completely self-contained unit in steel table frame. Has built-in motor to drive scraper-agitator, pump for recirculating contents. Insulated, thermostatically controlled gas heat.

**7 • DRI-JAR.** For preservation of specimens—metallurgical, chemical, biological, etc., Bethlehem Apparatus Co. makes a new container for storing material in a dry atmosphere. Called a Dri-Jar, it consists of wide-mouthed glass jar 3 in. in diameter, 7 in. high with a screw lid. Rigidly suspended from the lid is a series of four metal storage shelves. Material placed on the shelves is kept dry by a layer of

desiccating material in the bottom of the jar.

**8 • COUNTER FOR RADIOACTIVE LIQUIDS.** To simplify work with solutions containing radioactive materials, Nuclear Instrument and Chemical Corp., features a counter with a special Marinelli-type beaker. Geiger tube used as a dip counter.

**9 • CONTINUOUS BLOW-OFF.** For removing concentrated impurities from boilers by means of blow-off, the Uniblow Valve Co. developed a continuous system of draining boiler waters, 4 in. to 6 in. below surface. Uses a control disc with 15 calibrated orifices which may be quickly adjusted to permit any required flow. The orifices are indexed in pounds of water per hour and are rotated depending upon the concentrations of solids in the boiler. Sediment chamber protects the orifices. To 1000 lb./sq.in.

**10 • PUMP WITH EXCHANGEABLE ROTORS.** To reduce time of pump maintenance, DeLaval Steam Turbine Co. will be in production in September with a new type GS pump. All parts except pump casing are contained in a rotor assembly which can be removed for maintenance and repair work outside of the pump. A new rotor assembly can be dropped into the pump cas-

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ing, so that the down time is reduced. Three sizes for capacities to 450 gal./min. and heads up to 250 ft.

**11 • SELF-PRIMING PUMP.** Goulds Pumps, Inc., have patented a new line of self-priming centrifugal pumps. The pumps have no valves, no priming reservoir, and are made in sizes from 1/2 hp. to 5 hp. with open and closed impellers. Capacities of 120 gal./min. and heads to 135 ft.

**12 • PROPORTIONING VALVE.** For pipe lines and equipment requiring straight line proportional flow, W. S. Rockwell Co. has designed an automatic control valve using a slide valve in a rectangular orifice. As the slide is moved over the opening, the flow is directly proportional to the open area. Made from various metals, and built for pipes from 1/4 in. to 2 in., pressures to 300 lb./sq.in.

**14 • SMALL WATER SOFTENER.** A zeolite softener for small boiler and industrial plants, with requirements under 100 gal./min. is newly designed by Cochrane Corp. In several different sizes, various types of water-softening materials—zeolite, green sand, synthetic resins, etc. Diameters of tanks varies from 12 in. to 48 in., heights from 5 ft. to 6 ft. Bulletin available.

## CHEMICALS

**20 • ETHYLENE TRITHIOCARBONATE.** Stauffer Chemical Co. in production with this compound. For use as an intermediate in the manufacture of organic chemicals, in the vulcanization of rubber, as a flotation agent, sulfur solvent, and as an ingredient for pressure lubricants. More data on physical properties, reactions, etc., available from the company.

**21 • ROSIN ESTER.** A data sheet on fortified rosin ester in wax emulsions, from the resinous products division of Rohm & Haas Co. The rosin ester is used to give leveling and high gloss properties to wax emulsions, eliminating high spots and streaks. Publication gives physical properties, methods of preparing emulsions, etc.

**22 • SODIUM DISPERSIONS.** To give rapid, easily controlled sodium reactions, the National Distillers Chemical Corp. has evolved a new technique of making fine subdivisions of sodium, in inert media such as toluene, xylene, kerosene, etc. The corporation has prepared typical equipment layouts for users' guidance; has developed a special colloid mill setup for production of large quantities of sodium dispersions. According to the company, the use of sodium is facilitated since

reaction temperatures are lowered. Reactions listed.

**23 • PRECISION INSTRUMENT OILS.** For precision instruments, Gulf Oil Corp. through its Research Fellowship at Mellon Institute, has developed a special instrument oil and a microbearing oil, wholly synthetic, which are designed for special use on delicate, low-torque bearings encountered in precision instruments. Oils have no creeping or spreading tendencies and stay where placed. Resistant to oxidation, low in volatility, with a minimum of gumming. Packaged in 5 cc. bottles.

**24-25 • ALIPHATIC AMINES.** Two new primary aliphatic amines, tertiary-octylamine and Alkylamine 81 (a mixture of highly branched primary amines with the number of carbon atoms varying from 12 to 15), are new with the Rohm & Haas Co. (24) has a boiling point of 140° C., and (25) Alkylamine 81 has a boiling range of 220° to 260° C. Both are supplied as liquids. Physical data and information are available in company bulletins which give uses in the synthesis of insecticides, bactericides, wetting agents, textile finishes, detergents, pharmaceutical and corrosion inhibitors for metals.

**26 • HOMOPHTHALIC ACID.** By the Smith-New York Co., Inc., homophthalic acid a synthesis of a product which occurs naturally in gum gamboge resin. Data sheet gives physical properties, reactions, etc.

**27 • HEXYLENE GLYCOL.** Shell Chemical Corp. has a new booklet on hexylene glycol describing the solvent power, coupling ability, and other general properties of this petroleum-derived organic chemical. Applications to brake fluids, printing inks, as a coupling solvent in wood treating, etc., physical properties, specifications, stability, etc., are all given in this 28-page bulletin.

**28 • ISOPROPYL BENZOATE.** Commercial quantities of isopropyl benzoate are now being manufactured

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**29 • DHQ.** Edwal Laboratories, Inc. are in pilot plant production of 2,5-Dihydroxy 1,4-Benzquinone. DHQ forms a stable complex with metal ions, and will be used as an antioxidant and stabilizer in plastics and oils, as an organic carrier for heavy metals. Data sheets available.

**30-31 • ALKYL PHOSPHATES.** Monsanto Chemical Co. with two data sheets on alkyl phosphates,—both the alkali and acid types. Both give physical properties of various phosphates. (30) covers the alkali group of ammonium ethyl phosphate, amyl potassium sodium phosphate and various others. The acid booklet (31), covers methyl acid phosphate, ethyl, *n*-propyl, etc. Typical physical values are given for each of the compounds along with suggested uses, how shipped, etc.

## BULLETINS

**35 • AUTOMATIC TITRATOR.** A technical bulletin and price sheet on Beckman automatic titrators, by the National Technical Laboratories. Gives complete details about the construction of the automatic titrator which utilizes potentiometric methods. Has accuracies up to 0.1%. Does neutralization, oxidation-reduction, precipitation, and special titrations.

**36 • STEEL-BELT CONVEYORS.** For handling foods, chemicals, bakery products, etc., Sandvik Steel, Inc., has issued a bulletin describing its steel belt conveyors. Either carbon or stainless steel, with flat or troughed belts, with or without cooling. Standard sizes from widths of 8 in. up to 16 in. The bulletin shows many features including a patented water bed conveyor.

**37 • HIGH PRESSURE CONTROL VALVE.** Diaphragm valves for con-

trol purposes with a valve position indicator, stainless steel plug stems, guide bushings, seat rings, etc., are the subject of a new bulletin by Mason-Neilan Regulator Co. Sizes from 1 in. up to 2 in. with ratings from 1000 to 3000 lb./sq.in. for globe types, and 1500 to 6000 lb./sq.in. for angle types. Diaphragm motor is air operated with a diaphragm of neoprene rubber.

**38 • PNEUMATIC TRANSMITTER.** For measuring pressure, vacuum, specific gravity and liquid level, Instruments, Inc., describes in a new bulletin its F-C Series 5000 transmitter. The principle used is a force balance air flow. Five different unit assemblies for various applications. Range of measurement and data given. Covers specification, applications, and diagrams show the installation for various applications.

**39 • INFORMATION BULLETIN.** J. F. Pritchard & Co., an engineering construction firm, has a descriptive bulletin showing what services it offers to the chemical, gas, petroleum and power industries. Illustrated, shows typical construction of the units, types of plants, as well as equipment manufactured.

**40 • MINIATURE BULLETIN.** A new idea in industrial bulletins from the Sturtevant Mill Co. shows min-

ature reproductions of all the bulletins it offers. Full-size bulletins will be sent upon request, and this particular offering covers crushing, grinding, separating, elevating, conveying, and mixing machines made by the Sturtevant Co. The bulletins give typical data for all the equipment described.

**41 • ANTI-CORROSION WHITE.** A white enamel for inside or outside application in corrosive situations is described in a new bulletin of the Prufcoat Laboratories, Inc. Water-proof and non-toxic. Of value in laboratories, chemical plants, food plants, etc., where a white surface that resists corrosive action (acid, alkali) is needed.

**42 • ALUMINUM HEAT-EXCHANGER TUBES.** Aluminum Co. of America, in an extensive bulletin on aluminum heat-exchanger tubes made to A.S.T.M. specifications B234-48T. Shows fabrication and discusses inhibitors, cathodic protection, tube cleaning, application to heat exchangers, effect of corrosive chemicals on aluminum, how to design and fabricate a heat exchanger, fluid-flow characteristics, etc. Extensive tables of data and working pressures, tensile properties, etc.

**43 • DISTILLATION ENGINEERING.** A bulletin on the process design of distillation processes and equip-

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ment from Vulcan Copper & Supply Co. Covers packed column, sieve tray, bubble cap, etc. Column sizing, design factors, equipment fabrication, and mechanical design are discussed.

**44 • WIRE CLOTH.** An 85-page bulletin by The Cambridge Wire Cloth Co. on applications of wire cloth, metallic screens, etc. Bulletin covers data on types of weave, gives physical properties, as well as weights, areas and sizes, for all weaves. Pictorializes products made. Has an extensive discussion of metals and alloys and corrosive properties and other engineering tables.

**45 • 46 • 47 • VARIDRIVE MOTORS.** For the plant with the need to incorporate varied speed in driving equipment such as agitators, fans, etc., three pamphlets from the U. S. Electrical Motors, Inc., describing the Varidrive motor, will be of help. The first (45) describes machine production. Speeds are infinite from 1 to 10,000 rev./min. in a 1/4 to 50 hp. motor. Use a micro-speed control which changes the constant speed of the motor to variable speeds at the take-off shaft. (46) gives more data and shows the construction of the motor, the principle of operation, plus photographs of its application. (47) describes the regular line of motors by this company, including the Varidrive, synchrogear, and others.

**48 • PIPING PRODUCTS.** A huge, 200-page catalog of piping products made by the Midwest Piping & Supply Co., Inc., covers welding fittings, forged steel flanges, prefabricated piping, pipe coils. Physical data, weights, dimensions, strengths of all products, plus A.S.T.M. specifications for types of pipe, chemical

analysis, allowable stresses, design formulas, etc.

**49 • CENTRIFUGAL PUMP CATALOG.** Tri-Clover Machine Co. catalog on centrifugal pumps for sanitary use. Describes use of pump. Charts on loss of head due to friction, viscosity of fluids, conversion charts, and a brief section on correct hookup of centrifugal pumps for suction and discharge. Capacity curves are given.

**50 • COST COMPARATOR.** For comparing the material costs and properties of plastics and alternate materials such as aluminum, zinc, copper, nickel, wood, steel, etc., the plastics division of Monsanto Chemical Co. has a two-dial Comparator which gives easy reference to all plastics and 11 other structural and fabricating materials. The Comparator tells the specific gravity, cost per pound, cubic inch per pound, cost per cubic inch of plastics molding powders and the alternate materials.

**51 • RADIANT GLASS PANELS.** A new concept as a heat source for industrial application, is described in a bulletin of the Corning Glass Works, on radiant glass panels. Essentially, Pyrex glass with an electrically conducting coating on the surface. The radiation panel has been used in industrial applications such as yarn drying, drying lacquer, petroleum dehydration, and the bulletin suggests other uses. Standard sizes and ratings are given. Can be made to operate on 115 to 230 a.c. voltage. Size and shape of the glass may be varied. Electrical resistance of the coating can be controlled.

**52 • BULK STORAGE OF PLASTICIZERS.** The Monsanto Chemical

Co. issues another technical bulletin on storage of tank-car quantities of chemicals. This describes how to store plasticizers. Briefly outlines a system, includes drawings of typical equipment, arrangement, data on various properties of plasticizers.

**53 • LIQUID-LIQUID EXTRACTION.** An Otto H. York Co., Inc., publication on the York-Scheibel liquid-liquid extraction equipment. The Scheibel extraction column makes use of mechanically agitated mixing sections, followed by packed settling sections. Bulletin covers theory, gives data on operation, describes separation, number of stages, etc.

**54 • EYE PROTECTION.** A special pamphlet for the chemical industry, by the American Optical Co., which suggests types of eye protection to use. Lists chemicals and relates them to the severity of eye injuries. Bulletin is rounded out with the various types of chemical goggles.

**56 • 57 • SELF-LUBRICATING PACKINGS.** For seals on pumps, valves, shafts, etc., Greene, Tweed & Co. have published two new bulletins on self-lubricating packings. (56) Several different types of solvents, noncontaminating pump service, cold water, acid handling, alkali, steam water, etc. Also a bulletin (57) on sheet packings, asbestos, fiber, blue-asbestos, red-rubber, etc., for all applications requiring packings and gaskets.

**58 • MIXERS.** A high capacity, motor driven mixing unit which can be fitted to a variety of tank sizes, is described in a new Dorr Co. bulletin on flash mixers. Used for rapid diffusion of chemicals through water. The impeller is of the turbine type and the mixer is designed to work on tanks that have either underflow feed or side feed. Bulletin also describes Dorr Flocculators, etc.

**59 • PIPE LINES OF AMERICA.** A pictorial manual by the Nordstrom valve division of Rockwell Manufacturing Co., on the pipelines in the United States, moving natural gas, crude oil and products. The book covers Nordstrom valve design; shows the basic principles and other data on this type of valve, gives dimensions and availability, plus data on operations of the valves in pipelines. Page after page of illustration of typical pipelines, valve installations, makes for a manual that should be of interest to all engineers in the pipeline field.

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### Chemical Engineering Progress

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New York 17,

New York



## LETTER TO THE EDITOR

(Continued from page 23)

given to a code of ethics, formal training in that code, and strict enforcement of it. If mere skill, excellence in workmanship, degree of training, etc., are the extent of our efforts, then the fact that we have a measure of skill and use it to make a living has long prior to this time conferred the name of "professional" upon us.

Robert A. Sturges  
Solon, Ohio

July 3, 1950

### 1949 BOOK OF A.S.T.M. STANDARDS ISSUED

The 1949 Book of A. S. T. M. Standards in six parts is now available. It covers more than 8000 pages, and gives in latest approved form 1550 standards, specifications, tests, definitions, etc. Each part is complete with detailed subject index, two tables of contents, and arranged to provide technologists and others in industry and government with a usable book.

The six parts cover the following:

- Part 1. Ferrous Metals
- Part 2. Non-Ferrous Metals
- Part 3. Cement, Concrete, Ceramics, Thermal Insulation, Road and Waterproofing Materials, Soils
- Part 4. Paint, Naval Stores, Wood, Adhesives, Shipping Containers, Paper
- Part 5. Textiles, Soap, Fuels, Petroleum, Aromatic Hydrocarbons, Water
- Part 6. Electrical Insulation, Plastics, Rubber.

A complete set of all six parts costs \$54. Parts can be purchased separately. As a service with the 1949 Book of Standards there is a complete Index to Standards, which is furnished without additional charge. Copies may be obtained from the American Society for Testing Materials, 1916 Race Street, Philadelphia 3, Pa.

### CH. E. STUDENT GETS T.U.'S 50,000 DEGREE

The 1949-50 president of the campus chapter of the American Institute of Chemical Engineers recently received the 50,000th degree conferred by the University of Texas. He is Jack Keller of Dallas, a chemical engineering student. Departing from the custom of conferring degrees en masse upon candidates from the university's schools and colleges, officials called Keller from the college of engineering group for a special citation. President T. S. Painter presented Keller with a letter of congratulations and best wishes written personally by him on parchment. The award came as a complete surprise to Keller, whose name, listed alphabetically on the Commencement program, made him automatically the recipient of the university's 50,000th degree.

## Operators Say:

*"Annin Domotor Valves  
Cut Maintenance Cost  
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Actual users who compared Annin Domotor Valves with other standard valves report savings of 83% in maintenance costs. They learned from experience that the built-in ruggedness and simplified maintenance features of Annin Domotor Valves assure long, efficient, trouble-free service.



## Here are The Reasons:

**THEY'RE SINGLE SEATED**—Annin Domotor Valves are of proven, simplified single-seat design. The smooth, curved contour of the flow passages, without pockets or shoulders, provides free, uninhibited fluid flow for effective control of slurries, sludges and viscous fluids. Pressure drop and turbulence are reduced to a minimum and flow capacity greatly increased. The valve seat, clamped in position between the two sections of the separable valve body, absorbs all line stresses in shear for greater valve strength. Simplified construction cuts valve body weight by over 50%.

**THEY'RE CORROSION AND EROSION RESISTANT**—Annin Domotor Valves are available in the alloy that will give longest valve life under severe corrosive, erosive, or gaseous conditions. The wide range of alloys offered includes: Cast Carbon Steel, Cast Type 316 Stainless, Hastelloy B and C, Monel, Ampco 15, Annico 20 (D 20), Zinc Free Bronze, 98% "A" Nickel and almost any castable alloy. High velocity fluids are efficiently handled at temperatures from -300° F. to 1,000° F. and pressures to 2,500 lbs.

**THEY'RE SIMPLIFIED FOR FAST, ON-THE-JOB MAINTENANCE**—Any part of the Domotor valve body assembly or operating unit may be replaced or repaired while in the line, for maximum maintenance economy. Interchangeable line flanges make possible the use of a single valve anywhere in your plant, irrespective of system pressure. The separable valve body construction with threadless valve seat assembly permits immediate, on-the-job replacement or repair of the valve seat plug and stem without special tools or shop operations.

The floating, threadless valve stem guide, the only other wearing unit in the body assembly, is readily replaced by simply removing the valve stem packing. All parts of the Domotor assembly are made accessible by removing the snap ring which holds the unit together. Sealing "O" rings with molded-in lifetime lubrication, provide long wearing life of the operating assembly.

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## CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E. which states:

Election to membership shall be by vote of the Council upon recommendation of the Com-

mittee on Admissions. The names of all applicants who have been approved as candidates by the Committee on Admissions, other than those of applicants for Student membership, shall be listed in an official publication of the Institute. If no objection is received in writing by the Secretary within thirty days after the mailing date of the publication, they may be declared elected by vote of Council. If an objection to the election of any candidate is received by the Secretary within the period specified, said objection shall be referred to the Committee on Admissions, which shall investigate the cause for such objection, holding all communications

in confidence, and make recommendations to the Council regarding the candidate.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before Sept. 15, 1950, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st St., New York 17, N. Y.

### APPLICANTS FOR ACTIVE MEMBERSHIP

R. Burnell Bennett, Baytown, Tex.  
Charles A. Blaisdell, Chicopee Falls, Mass.  
Francis H. Bratton, Wilmington, Del.  
Arthur R. Broadman, New York, N. Y.  
A. J. Brockwell, Stockton-on-Tees, England  
Joe N. Butler, St. Louis, Mo.  
S. L. Carter, Boston, Mass.  
Peer J. Cody, Huntington, W. Va.  
Norman A. Copeland, Wilmington, Del.  
Lawrence J. Coulthurst, New York, N. Y.  
Robert S. Custer, No. Palo Alto, Calif.  
Joseph A. Dennis, South Gate, Calif.  
L. L. Fellingner, St. Louis, Mo.  
Robert W. Gaines, New Haven, Conn.  
Hollis T. Galley, Penfield, N. Y.  
Marshall C. Guthrie, Jr., Charleston, W. Va.  
Richard W. Hockman, Downey, Calif.  
Hazen Ray Hopkins, Argo, Ill.  
Femore C. Hoshour, Berkeley, Calif.  
Paul H. Kimpel, St. Louis, Mo.  
Charles O. King, Chattanooga, Tenn.  
Bruce G. Nanney, Canton, N. C.  
Fred C. Neuhart, Bartlesville, Okla.  
William W. Palmquist, Cleveland, Ohio  
M. M. Rama Rao, Bombay, India  
Harold W. Scheeline, Linden, N. J.  
Hans G. Schleicher, Texas City, Tex.  
Arch Chilton Scurlock, Alexandria, Va.  
John M. Seabrook, Bridgeton, N. J.  
John Shacter, Oak Ridge, Tenn.  
Randall D. Sheeline, Arlington, Va.  
Irving Shults, New York, N. Y.  
R. Philemon Stout, Philadelphia, Pa.  
W. C. Strader, Baton Rouge, La.  
Lynn R. Strawn, Port Neches, Tex.

Robert E. Weis, Phillips, Tex.  
Einar West, Wilmington, Del.  
J. P. Zeigler, Jr., Joliet, Ill.

### APPLICANTS FOR ASSOCIATE MEMBERSHIP

Robert J. Armstrong, Austin, Tex.  
Melbourne L. Jackson, Boulder, Col.  
James F. Elrod, El Dorado, Ark.  
Joseph J. First, Chicago, Ill.  
Vernon R. Gutman, Pelham, N. Y.  
George C. Hahn, Denver, Col.  
H. R. Kamath, Brooklyn, N. Y.  
Lester R. Sagar, Evanston, Ill.  
Jerome C. Wroblewski, Texas City, Tex.

### APPLICANTS FOR JUNIOR MEMBERSHIP

James Alexander, Port Arthur, Tex.  
George B. Allen, Manchester, Conn.  
Joseph P. Allen, Easton, Pa.  
Umberto Ancona, New York, N. Y.  
Cyril C. Baldwin, Jr., So. Orange, N. J.  
Alan G. Bates, Auburndale, Mass.  
Frederick M. Bertsch, Livingston, N. J.  
Joseph H. Bilberry, Jr., College Park, Md.  
B. G. Brawley, Decatur, Ga.  
William J. Burmeister, Whiting, Ind.  
Joseph Sherman Busch, Frederick, Md.  
Chian-Yuang Chen, Syracuse, N. Y.  
C. O. Chichester, Richmond, Calif.  
Theodore D. Cleary, E. St. Louis, Ill.  
Howard L. Cook, Bronx, N. Y.  
R. S. Cornell, Montreal, Que.  
Jasper J. Correnti, Cambridge Hts., N. Y.  
Charles T. Cross, Washington, D. C.  
Samuel Dane, Cuyahoga Falls, Ohio

Roy Davis, Milford, Ohio  
Lester R. Dawson, So. Houston, Tex.  
Louis H. T. Dehmow III, Chicago, Ill.  
James F. Derry, Forrest Park, Ill.  
Anderson Dye, Urbana, Ohio  
Wilson L. Dyer, Texas City, Tex.  
Leslie Ivan Edgcomb, Knoxville, Pa.  
Henning W. Eklund, Houston, Tex.  
Peter Eustis, W. Norfolk, Va.  
Syed Fareeduddin, Ann Arbor, Mich.  
Oscar James Fisher, Chicago, Ill.  
Leonard O. Frescoln, Euclid, Ohio  
Carl W. Fullerton, Philadelphia, Pa.  
Hal G. Garner, Carthage, Mo.  
Lester C. Gerard, Jr., New Orleans, La.  
Alice H. Goldberg, Los Angeles, Calif.  
Arvid W. Gorline, St. Louis, Mo.  
George A. Green, Niagara Falls, N. Y.  
Robert A. Hard, Cambridge, Mass.  
Harold W. Herbert, Midland, Mich.  
Howard Alfred Hittner, Brooklyn, N. Y.  
Alexander W. Hodge, Jr., So. Ozone Park, N. Y.  
Edgar Howard Hoffer, Los Angeles, Calif.  
John Isler, Jr., W. Lafayette, Ind.  
George D. Kellen, Jr., Valdosta, Ga.  
Arthur J. Kerbecok, Jr., Glenwood Landing, L. I., N. Y.  
Lynn R. Kinnamon, Philadelphia, Pa.  
Roger B. Knowles, Shamokin, Pa.  
Charles A. Lavery, Tulsa, Okla.  
Robert Wayne MacDonald, Baton Rouge, La.  
John L. Macintyre, Aurora, Ill.  
Michael N. Mallis, Baltimore, Md.  
Monroe Malow, Beacon, N. Y.  
Alston F. Manning, Glenview, Ill.  
Bernardo J. G. Mascarenhas, Rio de Janeiro, Brazil

Joseph A. McAnally, Brooklyn, N. Y.  
Harold W. McCaskey, Lander, Wyo.  
Herbert C. McKee, Columbus, Ohio  
Robert C. Michel, Woodhaven, N. Y.  
J. S. Miller, St. Albans, W. Va.  
Donald F. Molino, Troy, N. Y.  
Lyman W. Morgan, Muskogee, Okla.  
John D. Mueller, Baton Rouge, La.  
David R. Nalven, Newton, Conn.  
Robert A. Nance, Harts-ville, So. Carolina.  
Robert J. O'Donnell, Inglewood, Calif.  
L. P. Pasquier, Oak Ridge, Tenn.  
Ernest Maxim Peres, Jr., New Orleans, La.  
Robert E. Perry, Verona, N. J.  
Edward R. Peterson, E. St. Louis, Ill.  
R. Walter Peterson, Jr., Ann Arbor, Mich.  
John A. Prevel, Detroit, Mich.  
R. J. Rathi, Columbus, Ohio  
Kenneth Raven, Victoria, Tex.  
H. Robert Sanders, Blackburg, Va.  
Frederick A. Saporito, Hoboken, N. J.  
Edward B. Saubestre, Elmhurst, N. Y.  
Herbert G. Schultz, Jr., E. Chicago, Ind.  
Robert L. Schwenkmeier, Los Angeles, Calif.  
Karl G. E. Sharke, Troy, N. Y.  
Curtis Smith, Whiting, Ind.  
Harold P. Smith, Hamden, Conn.  
Peter W. Smith, Cleveland, Ohio  
Hugh Spencer, Niagara Falls, N. Y.  
Robert E. Stabler, Chadds Ford, Pa.  
Norbert F. Stasiak, Buffalo, N. Y.  
Ernest Steinmann, New York, N. Y.  
Edward Stern, Baltimore, Md.  
Arthur J. Stock, Detroit, Mich.  
Robert E. Stroup, St. Louis, Mo.



John F. Tattersall, Pitts-  
burgh, Pa.  
George W. Taylor, Jr.,  
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more, Md.  
Courtney M. Turlington,  
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Mich.  
George Edward Wise, Jr.,  
Syracuse, N. Y.  
Franklin W. Wyatt, Chi-  
cago, Ill.

## SECRETARY'S REPORT

THE Executive Committee met at the Offices of the Institute July 7. The Minutes of the June meeting of the Executive Committee, the Treasurer's Report, and bills were approved.

Because no adverse comments had been received on any of the candidates listed in the June C.E.P. all those whose names appeared there were elected to the grades of membership as indicated.

Paul B. Stewart was added to the Chemical Engineering Education Projects Committee, and V. D. Donihee and J. M. Mallory were added to the Membership Committee. C. C. Furnas, J. C. Lawrence, R. H. Marks and I. E. Miller were added to Public Relations Committee.

G. Beyer of Iowa State College was appointed counselor of the student chapter to succeed B. F. Ruth; also D. C. Davis was appointed counselor of the student chapter at the University of Denver to succeed L. E. Savory.

Six resignations from membership were accepted and one election was rescinded.

Following the meeting the agenda for the Council meeting was reviewed and many items discussed.

The Council met at The Chemists Club on the afternoon of July 7 and after disposing of the routine matters, the regular agenda was followed. The first item was Student membership and the following were approved as the rules governing Student membership:

1. Annual dues shall be \$1.00 and memberships shall expire on Dec. 31. The dues would not be prorated in cases where the membership term was less than one year.
2. There shall be no entrance fee.
3. Student members shall have the privilege of subscribing to C.E.P. at the special rate of \$3.50 a year on a calendar year basis. This subscription rate shall be prorated in the case of subscriptions running less than one year.
4. The emblem (badge, charm, or pin) should be sold on the same basis as are the emblems for the other grades of membership.
5. If a Student member applies for Junior membership prior to the expiration of his Student membership he shall pay as entrance fee the difference between the dues paid as a Student member and the Junior membership entrance fee.
6. The student registration fee at regional and national Institute meetings shall not be waived.
7. Student members shall be eligible to participate in the activities of local

sections on the same basis as the members of all other grades.

8. Conditions under which the Student members participate in meetings arranged by or for student chapter members shall be determined by those arranging for such meetings.

The Council also voted that the Student membership would be given to that member of the Junior class who had the highest scholastic standing in his freshman and sophomore years.

W. E. Lobo was present at Council by invitation to present a proposal that the Institute establish a Committee on Research. The duties of this Committee would be to determine the specific fields of chemical engineering in which fundamental research should be carried on; and to sponsor such research with the financial assistance of the industry which would be particularly interested in the research project and to whom the data obtained would be of value. It was voted that a Committee on Research be established and that W. E. Lobo act as chairman of this committee, and that he suggest for appointment additional personnel for the committee.

Council has had before it for some time the question of the remission of dues of members under certain specific circumstances and the following has been set up as a bylaw:

### Remission of Dues

1. The Council by a two-thirds vote may remit dues of any member where the circumstances justify: (Present by-laws.)
2. After payment of dues for a period of 25 years, a member who feels he is unable to continue payment of dues may, upon his written request, have his dues remitted with retention of membership in good standing.
3. A member who has been automatically retired (usually between the ages of 60 and 70 years) or who has been retired from active service by reasons of health may, upon his written request, have his dues remitted with retention of membership in good standing.
4. Members whose dues have been remitted shall be entitled to subscribe to publications of the Institute at the regular member rate.
5. All cases for remission of dues shall be considered on an individual basis by the Executive Committee, which shall make appropriate recommendation to Council for action.

The Secretary reported that 21 Active members, 4 Associate members and 133 Junior members had not paid their dues for 1949 and 1950; therefore the action of the Council was in accordance with

the Constitution to discontinue these memberships.

Secretary reported that a check in the amount of \$542.28 had been received from the committee handling the affairs of the Houston Regional Meeting and it was voted that this amount be credited to the Institute Meetings Account.

### Suggested Nominees for 1951-53 Directors

In April issue of C.E.P., p. 36, a notice appeared advising each of the local sections to suggest the name of a possible nominee for one of the four elected directors for a three-year term, starting Jan. 1, 1951, and stating that the nominations so obtained would be published in the August issue.

The purpose of this is to aid the members in the selection of nominees for directors as it was felt that a large portion of the membership did not vote because it did not have a logical nomination to make and in other cases votes were scattered to such an extent that they were literally wasted votes.

In accordance with the above procedure a letter was sent to each of the local sections and the list below is the result; where no suggestion was made and where no reply was received the name of the section has been omitted.

Akron—George Richard Lyon  
Boston—E. P. Stevenson  
Charleston—R. L. Sibley  
Chicago—Robert C. Gunness  
Cleveland—Curry E. Ford  
Columbia Valley—C. R. Nelson  
Detroit—Donald L. Katz  
Kansas City—C. W. Nofsinger  
Knoxville—Oak Ridge—Robert M. Boarts  
Maryland—E. W. Guernsey  
New Jersey—C. L. Brown  
New York—R. P. Kite  
Northern California—C. R. Nelson  
Ohio Valley—R. S. Tour  
Philadelphia—Wilmington—W. T. Dixon  
Pittsburgh—Richard D. Hoak  
Rochester—John H. Folwell  
South Texas—R. H. Price  
Southern California—C. R. Nelson  
Tulsa—Frank Jenny  
Twin City—E. L. Piret  
Western Massachusetts—J. S. Stanford

### 1950 YEAR BOOK

The Secretary's office has completed the distribution of the 1950 Year Book. The listing in this book carries the names of all members as of March 31, 1950. Will you please check your listing to make certain that it is as you want it. A blank was sent to all members in February and all changes requested are incorporated.

## NECHES GR-S PLANT TO OPEN

Reactivation of the GR-S synthetic rubber plant at Port Neches, Tex., by United States Rubber Co. will begin immediately as requested by the Reconstruction Finance Corp., according to company officers. It is expected that the plant will be in operation in about three months.

One of the first jobs will be to reassemble equipment which was dismantled and put into stand-by when the plant was closed after World War II.

The Port Neches plant has a rated capacity of 60,000 tons but J. P. Coe, vice-president and general manager of company's Naugatuck chemical division, said it will be possible to increase this to 75,000 tons if more is needed.

United States Rubber Co. is now operating a Government-owned synthetic plant at Naugatuck, Conn., with a capacity of 30,000 tons, and also a plant at Borger, Tex., with a capacity of 45,000 tons. The company will continue to operate the Borger plant until Port Neches is fully reactivated, after which operation of Borger will be turned over to the Phillips Chemical Co. All supervisory personnel at Borger will be transferred to Port Neches and additional personnel will be hired from the Port Neches area. The plant will employ about 450 persons.

## JOHN L. SMITH, PFIZER BOARD CHAIRMAN, DIES

John L. Smith, chairman of the board of Chas. Pfizer & Co., Inc., died July 10, after an illness of several months. A pioneer in the drug and chemical field, he played an important role in the development of the antibiotics.

Born in Crefeld, Germany, in 1888, and emigrating with his family at the age of two, he joined the Pfizer company as a laboratory assistant in 1906. In 1919 he was made superintendent of the Pfizer plant, a member of the board of directors in 1920, and progressed through various official positions until elected president in 1945. In 1949, he was made chairman of the board.

## VACUUM FLASHERS FOR S.O. CALIF.

Standard Oil Company of California has awarded a contract for what is considered the world's largest vacuum flashing unit able to charge 55,000 bbl. of reduced crude a day to The M. W. Kellogg Co.

According to Kellogg, the main vessel in the unit will stand 80 ft. high and will have a maximum diameter of 27 ft.

Its design capacity exceeds by 15% the largest vacuum unit now in operation.

The unit is being designed to provide approximately 30,000 bbl. of feed each day for the existing catalytic cracking unit at Richmond, which is scheduled for revamping during the modernization. Asphalt—the other major product from the flasher—will be charged to visbreakers to produce high quality fuel oil and gasoline.

Scheduled for completion in May, 1951, the new unit will charge not only reduced crude from California's Richmond and El Segundo refineries, but will also process some heavy, so-called "non-refinable" crudes.

## DU PONT MAKES SURVEY IN REACTOR ENGINEERING

The U. S. Atomic Energy Commission announced that the Du Pont Co., of Wilmington, Del., is making a special survey covering facilities, processes and technical problems in certain fields of chemical and reactor engineering.

The Du Pont Co. was builder and first operator of the Hanford plutonium production plant, having entered upon that project in 1942. In the fall of 1946, at the company's own request it withdrew from the project. Last year, however, Du Pont carried out for the Commission a special study of the chemical processes used in the production of plutonium.

The work involves analysis of a number of existing and planned projects in the expanding program of atomic energy development. Research and development work under way at many locations throughout the country will be covered by the survey, which includes process feasibility studies, developmental projects and facilities requirements.

## KELLOGG SELLS KELLEX CORP.

The Kellogg Corp., an important contractor in the atomic energy field, was sold last month to the Vitro Manufacturing Co. according to an announcement of Warren L. Smith, president of The M. W. Kellogg Co., who owned the stock and assets of the Kellogg Corp.

"This step," said Mr. Smith, "is in accord with Kellogg's policy of concentrating its commercial development, engineering and manufacturing efforts in the petroleum, chemical and power fields and of confining its governmental contracts to development engineering and manufacturing in the fields of jet propulsion, guided missiles, etc." These latter activities are conducted by Kellogg's special projects division in Jersey City.

Contracts currently held by Kellogg, primarily in the field of atomic energy, will be continued by that organization.

## LOCAL SECTION

### SOUTH TEXAS

This section held its monthly meeting and inspection trip June 16, 1950. The inspection trip was through the surface installations of the Gillock field in the vicinity of Texas City, Tex., of the Pan American Production Co., where the group saw various recycling and drilling operations used in the modern methods of producing an oil formation.

The social hour and dinner were held at the Edgewater Restaurant at Kemah, Tex. The speaker for the evening was the host for the inspection trip, J. L. Hoyt, assistant general superintendent of the production department of the Pan American Production Co., who spoke on the major problems encountered in the production of oil from Gulf Coast formations.

The inspection trip was attended by approximately 60 members; the dinner was attended by approximately 85 members.

*Reported by G. T. McBride, Jr.*

### NEW JERSEY

At the annual meeting the following officers were elected for the 1950-51 season:

*Chairman—F. J. Van Antwerpen, Editor, C.E.P.  
Chairman-elect—G. C. Keefe, Newark College of Engineering  
Secretary—E. P. Foster, Du Pont Co.  
Treas.—R. P. Smith National Lead Co.  
Exec. Comm.—D. S. Bruce, Hercules Powder Co.; D. M. Calkins, Merck & Co.; H. B. H. Cooper, American Cyanamid Co.*

During the course of the year ten meetings were held; two were organizational, and eight technical. The final meeting was held at the Esso Research Center at Bayway. Dr. J. C. Elgin of Princeton University spoke on "Some Theoretical Aspects of the Spray-type Liquid Countercurrent Contacting Equipment."

*Reported by H. Philip Orem*

### MARYLAND

At the May 11 meeting which closed the spring session C. F. Prutton, Mathieson Chemical Corp., Baltimore, Md. spoke on "Chemicals from the Sea." At the previous meeting J. H. Rushton, professor of chemical engineering, Illinois Institute of Technology, spoke on "The Technology of Mixing."

*Reported by Alan Beerbower*

## PITTSBURGH

The following officers for the 1950-51 session are elected:

Chairman.....Carl C. Monrad  
Vice-Chairman.....F. O. Calhoun  
Secretary (re-elected)...C. T. Barker  
Treasurer.....J. G. Bradshaw

In his address at a recent meeting Dr. J. H. Rushton discussed the factors influencing solid-liquid and gas-liquid types of mixing. Available pilot plant and experimental data were reviewed, and their application shown in the evaluation of equipment performance and process design. A color motion picture was presented.

*Reported by Hugh L. Kellner*

## THE CHEMICAL ENGINEERS' CLUB OF WASHINGTON

Officers elected for the forthcoming year are as follows:

Pres.—George Arnistead, Jr., Washington chemical engineer  
Vice-Pres.—Randall D. Sheeline, U. S. Dept. of Navy, Bureau of Ordnance  
Sec.—H. W. Yeagley, Monsanto Chemical Co., Washington, D. C.  
Treas.—W. D. Kavanaugh, American Cyanamid Co., Washington, D. C.

*Reported by D. O. Myatt*

## EL DORADO CHEMICAL ENGINEERS' CLUB

"Centrifugal Pumps—Their Design and Application" was the subject of a talk presented before this club at its June dinner meeting attended by 68 members and guests. Drew Whiting, sales engineer for Ingersoll-Rand Co., with headquarters in Dallas, Tex., was the speaker. He discussed the different types of centrifugal pumps currently being manufactured and the service for which each is intended.

At its May dinner meeting, 56 members and guests heard a discussion on "Sugar Manufacturing—Where Unit Operations Got Their Start" by Dr. Arthur G. Keller, professor of chemical engineering at Louisiana State University, Baton Rouge, La. In the field of evaporation, he said, the industry developed and introduced the single-effect vacuum pan and subsequently the multiple-effect evaporator. He amplified his remarks by the showing of slides and the passing of samples of cane sugar and its by-products in various stages of manufacture for the inspection of the group.

*Reported by E. D. Wurster*

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- OIL-BATH LUBRICATION OF ALL MOVING PARTS
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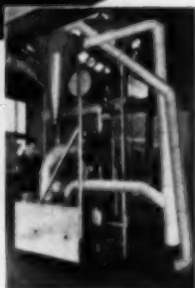
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## FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

George E. Holbrook

Room 7406 Nemours Bldg.,  
E. I. du Pont de Nemours & Co.,  
Wilmington, Del.

### MEETINGS

**Regional**—Minneapolis, Minn.,  
Radisson Hotel, Sept. 10-13,  
1950.

**Technical Program Chairman:** E. L.  
Piret, Minnesota Mining & Mfg.  
Co., Minneapolis, Minn.

**Annual**—Columbus, Ohio, Neal  
House, Dec. 3-6, 1950.

**Technical Program Chairman:** John  
Clegg, Battelle Memorial Institute,  
Columbus, Ohio

**Regional**—White Sulphur  
Springs, W. Va., The Greenbrier,  
March 11-14, 1951.

**Technical Program Chairman:**  
Walter E. Lobo, The M. W.  
Kellogg Co., 225 Broadway, New  
York, N. Y.

**Regional**—Kansas City, Mo.,  
Hotel Muehlebach, May 13-16,  
1951.

**Technical Program Chairman:**  
Walter W. Deschner, J. F.  
Pritchard Co., Kansas City, Mo.

**Annual**—Atlantic City, N. J.,  
Chalfonte-Haddon Hall Hotel,  
Dec. 2-5, 1951.

### SYMPOSIA

**Indoor vs. Outdoor Plant Con-  
struction**

**Chairman:** J. R. Minevitch, E. R.  
Badger & Sons Co., 75 Pitts St.,  
Boston, Mass.

**Meeting**—Minneapolis, Minn.

**Quantitative Economics in Esti-  
mation of Risk Factors in Capital  
Ventures**

**Chairman:** Mott Souder, Shell De-  
velopment Co., 100 Bush St., San  
Francisco, Calif.

**Meeting**—Minneapolis, Minn.

**Applied Reaction Kinetics**

**Chairman:** R. H. Wilhelm, Prince-  
ton (N.J.) University  
**Meeting**—Minneapolis, Minn.

**Chemical Engineering in Food  
Industries**

**Chairman:** W. L. Faith, Corn Prod-  
ucts Refining Co., Argo, Ill.  
**Meeting**—Minneapolis, Minn.

**Phase Equilibria**

**Chairman:** W. C. Edmister, Carnegie  
Inst. of Tech., Pittsburgh, Pa.  
**Meeting**—Minneapolis, Minn.

**What Should You Know About  
Management?**

**Chairman:** L. P. Scoville, Jefferson  
Chemical Co., Inc., 711 Fifth Ave.,  
New York 22, N. Y.

**Meeting**—Minneapolis, Minn.

**Air and Water Pollution Control**

**Chairman:** Richard D. Hoak, Mellon  
Institute of Industrial Research,  
University of Pittsburgh, Pitts-  
burgh, Pa.

**Meeting**—Columbus, Ohio

**Chemical Engineering in Glass  
Industry**

**Chairman:** F. C. Flint, Hazel-Atlas  
Glass Co., Washington, Pa.  
**Meeting**—Columbus, Ohio

**Processing of Viscous Materials**

**Chairman:** W. W. Kraft, The Lum-  
um Co., 420 Lexington Ave., New  
York, N. Y.

**Meeting**—Columbus, Ohio

**Phase Equilibria**

**Chairman:** W. C. Edmister, Car-  
negie Inst. of Tech., Pittsburgh,  
Pa.

**Meeting**—Columbus, Ohio

**Relationship Between Pilot-Scale  
and Commercial Chemical En-  
gineering Equipment**

**Chairman:** Walter E. Lobo, The M.  
W. Kellogg Co., 225 Broadway,  
New York, N. Y.

**Meeting**—White Sulphur Springs,  
W. Va.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, George E. Holbrook, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.



## CENTRAL VIRGINIA CHEMICAL ENGINEERS' CLUB

The following were elected officers for 1951:

*President*—R. R. James, Front Royal  
*Vice-President*—S. A. Lamanna, Piney River

*Sec.-Treas.*—E. H. Sundbeck, Waynesboro

*Directors*: J. D. Detlefsen, Waynesboro; E. L. Foerster, Elkton; Emil Hladky, Piney River; R. M. Hubbard, Charlottesville; E. W. Samoden, Piney River (Ex-officio)

The club held its 1950 annual meeting at the Keswick Country Club near Charlottesville, at which 45 members and guests were present. Dr. John H. Yoe, professor of chemistry at the University of Virginia and member of the technical observers group of Operation Crossroads at Bikini in 1946, presented the official movies of these A-bomb tests.

*Reported by J. D. Detlefsen*

## CHICAGO

At this section's recent annual meeting the following officers were elected for the term July 1, 1950, to June 30, 1951:

*Chairman*.....C. W. Peters  
*Vice-Chairman*.....D. A. Smith  
*Secretary*.....E. N. Mortenson  
*Treasurer*.....J. R. Blizzard  
*Director-at-Large*—M. J. Sterba (to 6/30/53); J. H. Rushton (to 6/30/52); W. L. Faith (to 6/30/51)

The technical program included a discussion on "Basic Design Problems in Nuclear Engineering" by John R. Huffman of Argonne National Laboratory.

*Reported by E. N. Mortenson*

## ROCHESTER

The annual banquet was held in Lorenzo's Restaurant, with an attendance of 97 members and guests.

Officers elected for 1950-51 are as follows:

*Chairman*—E. E. Mohr, Eastman Kodak Co.

*Vice-Chairman*—J. L. Patterson, Eastman Kodak Co.

*Secretary*—J. R. Connolly, Mixing Equipment Co.

*Treasurer*—R. R. Ross, Eastman Kodak Co.

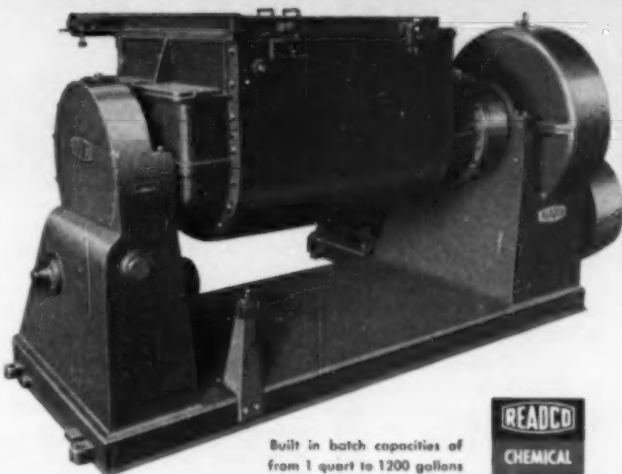
*Directors*—R. H. Pond, Taylor Instrument Co.; G. L. Calderwood, Rochester Gas & Elec. Co.

The first speaker, Carl H. Gath of Eastman Kodak Co., presented a review of a paper entitled "Psychological and Physiological Attributes of the Successful Chemical Engineer."

The main speaker of the evening, Dr. Harry A. Curtis, director of Tennessee Valley Authority, talked on "Facts and Fiction Regarding the T.V.A."

*Reported by John R. Connolly*  
(More Local Section on p. 38)

## Readco Double-Arm Mixers Speed Up Mixing Cycle, Minimize Peak Loads



Built in batch capacities of  
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### Overlapping sigma blade action assures a shorter mixing cycle with reduced peak loads

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## PEOPLE

### JESSE WERNER



Joseph Byrne was recently appointed assistant professor of chemical engineering at M.I.T. and will serve as director of the Buffalo Station of the school of chemical engineering practice. He will be located at the M.I.T. Station, Bethlehem Steel Co., Lackawanna, N. Y.

### ADVANCED BY DIAMOND



### J. E. UNDERWOOD

J. E. Underwood, manager of research of the Diamond Alkali Co., Cleveland, Ohio, for the past six years, has been named research consultant for the company. Previously Mr. Underwood had been manager of research and development for the Pennsylvania Salt Manufacturing Co., Philadelphia, for 16 years. From 1923-27 he was director of research for the National Lime Association, Washington, D. C. His research experience began in 1915 with a fellowship at Mellon Institute in Pittsburgh on a problem sponsored by the Hope Natural Gas Co., and subsequently included service with the U. S. Bureau of Mines in Colorado; the Radium Company of Colorado, and the Radium Emanation Corp. at Pittsburgh. Mr. Underwood graduated from Wabash College and received his M.A. there in chemistry. He supplemented this education with teaching fellowships at both Ohio State University and the University of Missouri. He is affiliated with a number of professional organizations.

### WERNER ADVANCED BY GENERAL ANILINE

Jesse Werner has been appointed assistant to the process development manager of the Grasselli works division, General Aniline and Film Corp. Prior to assuming his present position Dr. Werner had been a section leader on the process development staff for several years.

A graduate of Brooklyn College, cum laude, in 1935, Dr. Werner received his M.A. degree in 1936 and his Ph.D. degree in 1938 from Columbia University. He was an assistant in the chemistry department at Columbia from 1936-38. He joined the research department of General Aniline immediately after leaving the university.

Dr. Werner is a member of the Board of Editors of "Chemical Formulary" and the author of a number of sections in the "Encyclopedia of Chemical Technology" concerning dyestuffs.

### LANG IN NEW ROLE WITH GENERAL ANILINE

Joseph W. Lang was recently appointed manager of the Rensselaer dye-stuff plant of General Aniline and Film Corp. He attended the University of Washington where he received his degree of B.S. Ch.E. in 1928. He also attended Columbia University where he received his M.S. in 1933 and Ph.D. in 1934.

Following graduation, Dr. Lang did research on organic pigments and chemical engineering work for a major dye-stuff manufacturer. Dr. Lang joined the Rensselaer plant of the General Aniline works division as head of the chemical engineering group in 1943. Subsequently he was made supervisor of production, production manager, and assistant plant manager at Rensselaer.

### NEW APPOINTMENTS AT NAVAL ORDNANCE, CALIF.

Recent appointments have been made at the Naval Ordnance Test Station at China Lake and Inyokern, Calif. The appointees and their titles are:

- P. A. Longwell, head of ordnance processing
- K. S. Skaar, consultant to the head of ordnance processing
- J. H. Wiegand, head of propellants division
- Q. Elliott, head of solid propellants branch succeeding J. H. Wiegand
- E. T. Leidigh, head of process section
- F. A. Newburn, project engineer

## HERITAGE ADVANCED BY WEYERHAEUSER

Clark C. Heritage was recently named director of development for the Weyerhaeuser Timber Co. He will establish headquarters in the company's Tacoma (Wash.) general offices Sept. 1.

In 1937, Mr. Heritage organized the development of the Wood Conversion Co., Cloquet, Minn., a Weyerhaeuser affiliate engaged in the manufacture of wood fiber products. When the Weyerhaeuser Timber Co. became a separately managed activity in 1941, Mr. Heritage was selected to construct facilities at Longview, Wash. He has directed the development work for both companies since that date.

With an educational background of science at the University of Chicago and engineering at Armour Institute of Technology, Mr. Heritage has been in the production, sales, engineering, development and management phases of organic chemicals and forest products for many years. He served for an extended period as chief of engineering design and development for National Aniline and Chemical Co., Buffalo, N. Y. A few years later he directed the pulp and paper work of the Forest Products Laboratory of the U. S. Forest Service at Madison, Wis.

Elvin Nord, associate professor of chemical engineering, Wayne University, Detroit, Mich., recently received his law degree (LL.B.). He has also passed the examination for registration to practice as patent attorney before the Patent Office.

Howard Kehde, formerly with Foster Wheeler Corp., New York, N. Y., is now associated with the Union Oil Company of California, Wilmington, Calif. He is engaged in the research department.

Paul Kolachov, director of research for Joseph E. Seagram & Sons, Inc., was recently elected a state vice-president of the Southern Association of Science and Industry.

### C. C. HERITAGE



# SPARKLER *horizontal plate* FILTERS



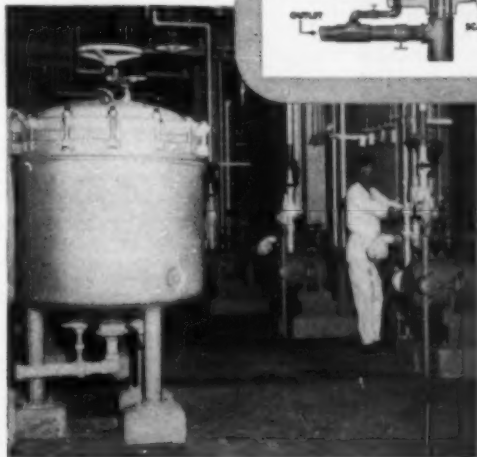
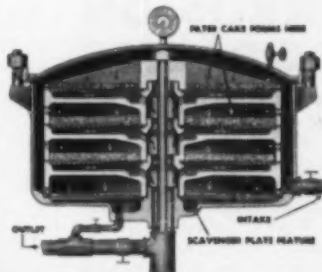
— preferred by many in chemical processing plants because of two outstanding features — uniform microscopic filtration — complete recovery of product.

Unlike the construction of some other types of filters the horizontal plates in the Sparkler allow the filter media to form in an even cake of uniform thickness, built up in a horizontal position without stress and therefore not subject to cracking or slipping under pressure, thus assuring uniform filtration either with intermittent or continuous flow.

Complete recovery of product is obtained by "wash through" or "blow down" of cake without removal from filter. The Sparkler scavenger plate, with independent control valve, acts as an auxiliary filter, filtering each batch down to the "last drop" leaving no holdover.

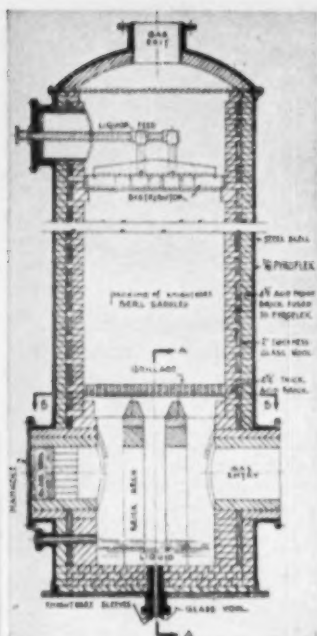
Plates are available in two thicknesses, deep plates for liquids carrying a large proportion of solids and shallow plates for polishing operations. When shallow plates can be used the filter area is increased within the same size tank.

This illustration shows a Sparkler filter installed in the plant of a large producer of insulating varnish. Standard models are available in capacities of 60 to 7,500 G.P.H.



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## J. W. PAYNE



John W. Payne has been made technical director of the development division of the research and development laboratories, Socony-Vacuum Oil Co., Inc. Mr. Payne received his B.S. degree in chemical engineering from Yale in 1930, and has been associated with Socony-Vacuum since 1931.

## RUEBENSAAL TO DIRECT PLASTIC RESEARCH

Appointment of Clayton F. Ruebensaal as technical director of plastics and resins for Naugatuck chemical division, United States Rubber Co., was recently announced. Mr. Ruebensaal will assume direction of all research, process development and technical service activities pertaining to Kralastic molding powders, Vibrin polyester resins, Marvinol vinyl resins and PQL resins for enamels. He will make his headquarters at the division's main plant in Naugatuck, Conn.

Mr. Ruebensaal was one of the organizers of the chemical division of the Glenn L. Martin Co., Baltimore, Md. He joined U. S. Rubber late in 1949 when the company purchased the assets of Martin's chemical division. In 1945 and 1946 he was one of a group of technical consultants who visited Germany at the invitation of the U. S. Government to study German methods of plastics production and research.

William H. Waite, formerly assistant technical director of Arthur G. McKee & Co., Cleveland, Ohio, is now a consultant in the engineering service division of the Du Pont Co., Wilmington, Del.

Joseph R. McCleskey, Jr., who previously served in a supervisory capacity in the Monsanto Chemical Co.'s plastics division headquarters at Springfield, Mass., has been appointed plant supervisor at the company's new styrene plant in Long Beach, Calif. He joined the plastics division in 1946, serving in technical and supervisory assignments. Until his present appointment he was a plant supervisor in the Springfield unit. Mr. McCleskey was graduated from Alabama Polytechnic Institute.

Louis F. Ray has been appointed development superintendent at Monsanto Chemical Co.'s John F. Queeny plant, St. Louis, Mo. Mr. Ray will succeed J. R. Okel, who has been appointed assistant to Dr. Charles Allen Thomas, executive vice-president. Mr. Ray is a graduate of St. Louis University, where he received a B.S. degree in chemistry in 1938. He went to Monsanto as an analytical chemist at the John F. Queeny plant, and became area supervisor in 1943. Since that time he has been in charge of three department groups consecutively.

Sydney Steele, formerly sales promotion manager, Fischer & Porter Co., Hatboro, Pa., is now associated with the Atlas Powder Co., Wilmington, Del. His position is manager, market research.

Carl R. Vander Linden, formerly an instructor in the chemical engineering department of the Iowa State College, Ames, Iowa, has recently become affiliated with the Johns-Manville Research Center of the Johns-Manville Corp. in Manville, N. J. He will engage in chemical engineering research.

L. M. Currie, vice-president, national carbon division, Union Carbide & Carbon Corp., N. Y., received a D.S. degree from Clarkson College of Technology, Potsdam, N. Y., on June 4. Joining National Carbon in 1925 as a research chemist, he became progressively plant superintendent; assistant director, research; director, vinylite division; superintendent, Bakelite division; and vice-president. He was associate director of War Research, Columbia University, 1943-45. Dr. Currie's early education was at Dublin Institute, Va., and Davidson College, N. C., where he received his A.B. in 1918 followed by a Ph.D. from Cornell University in 1925. He was a Sage Fellow in 1924-25.

Robert B. Beckman has been promoted to associate professor of chemical engineering at Carnegie Institute of Technology effective Sept. 1, 1950. Before joining the Carnegie faculty in 1946, he was a research chemist with Humble Oil and Refining Co., Baytown, Tex. Dr. Beckman holds a B.S. degree in chemical engineering from the University of Illinois and a Ph.D. from the University of Wisconsin.

C. O. Butler was recently elected vice-president and general manager of the General Foundry and Machine Co., Sanford, N. C. He was formerly associated with the consulting firm of Matthews & Butler, Engineers, and previous to that was superintendent of spinning in the acetate rayon division of Tennessee Eastman Corp.

## OKEL PROMOTED BY MONSANTO CHEM. CO.

Jean R. Okel, development superintendent in the Monsanto Chemical Co.'s John F. Queeny plant at St. Louis, has been named assistant to Charles Allen Thomas, executive vice-president. He succeeds Philip R. Tarr, who has been appointed to the new position of European technical representative with headquarters in Paris, France. Mr. Okel joined Monsanto in 1942 as a department supervisor in the Queeny plant and in 1946 was appointed project engineer of the plant development group. Subsequently he became assistant development superintendent and development superintendent. Before going to Monsanto he was employed in the industrial engineering department of the titanium division of National Lead Co. He received a B.S. in chemical engineering from Washington University.

Lincoln T. Work, consultant, who has been operating from an office in Maplewood, N. J., since severance from Powdered Material Research Laboratories in Cambridge, now has office space with Singmaster & Breyer (Room 2118), Graybar Building, 420 Lexington Ave., New York, N. Y. He can also be addressed at Maplewood.

### J. H. ROTHSCHILD



Lt. Col. J. H. Rothschild, who organized and commanded the Chemical Warfare Service Development Laboratory at Massachusetts Institute of Technology during World War II, and who recently was made Commanding Officer of Technical Command, a chemical corps research and development organization located at Army Chemical Center, Md., has been promoted to grade of Colonel.

After the war, Colonel Rothschild headed the technical division of the Office of the Chief of the Chemical Corps. He had been assistant professor of chemistry at the U. S. Military Academy for the last three years.

Colonel Rothschild received his B.S. degree upon graduation from West Point in 1930, and his M.S. degree in chemical engineering practice from Massachusetts Institute of Technology.



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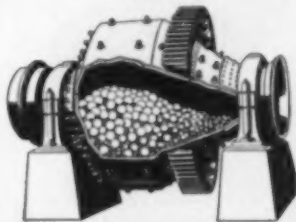
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E. I. CLAPP



*Bochrach*

Elwood I. Clapp recently assumed  
the position of vice-president in charge  
of sales of the Badger Manufacturing  
Co., Cambridge, Mass. Since the or-  
ganization of that company in 1949 he  
has been serving as a director. Mr.  
Clapp was graduated from the Uni-  
versity of Maine with a B.S. degree in  
chemical engineering, and subsequently  
became associated with the U. S. Indus-  
trial Chemicals, Inc., Baltimore, Md.,  
where he remained for seven years. For  
the past 25 years he has served E. B.  
Badger & Sons Co., Boston, Mass., in  
the engineering and sales department.  
He was engaged especially in the de-  
signing of equipment for their own  
manufacture.

Charles H. Stockman is now with  
the B. F. Goodrich Research Center,  
Brecksville, Ohio, as a research chemical  
engineer. He received his B.S. in 1947  
from Purdue and his Ph.D. this year.

C. J. MAJOR



Coleman J. Major has been ap-  
pointed associate professor of chemical  
engineering at the State University of  
Iowa, Iowa City, Iowa. Dr. Major  
received his B.S. degree in chemical  
engineering from the University of  
Illinois in 1937, and his Ph.D. from  
Cornell University in 1941. During the  
past nine years he has been with  
Sharples Chemicals, Inc., at Wyand-  
otte, Mich., where he resigned recently  
from his present position as superinten-  
dent of the service department. His  
appointment at the university of Iowa  
becomes effective in September.



## CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance, and are placed at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line insertion free of charge per year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements one-inch deep are available at \$15 an insertion. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress, Classified Section, 120 East 41st Street, New York 17, N. Y. Telephone ORgon 9-1540. Advertisements for this section should be in the editorial office the 25th of the month preceding the issue in which it is to appear.

### SITUATIONS OPEN

#### PRESSURE VESSEL DESIGN ENGINEER

Excellent opportunity in well-known oil refinery company for graduate engineer with heavy experience in design and development.

Familiar with ASME and API Codes and the work of the Pressure Vessel Research Committee. Knowledge of vessel fabricator's shop practices and metallurgy including welding of carbon and alloy steels.

Write details of education and experience to Box 4-8.

#### INSTRUMENT ENGINEER

Excellent opportunity in well-known oil refinery company for graduate chemical engineer.

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**Supervising Chemical Engineer**—Chemical Engineering Degree, preferably Ph.D. 35 to 45 years of age. Approximately 15 years experience in organic chemical industries, preferably intermediates or dyestuffs. Thoroughly experienced in applying chemical engineering principles to production problems in batch process type of industry. Permanent position in well-established company in upstate New York. Send complete business resume and salary requirements. All replies confidential. Box 1-8.

**Chemical Engineers and Chemists**—For research and development of organic chemicals in laboratory and pilot plant. Permanent employment. M.S. degree preferred. Will consider B.S. degree with experience or exceptional scholastic record. Location Corpus Christi area. Preference given to applications from Texas, Oklahoma, and Louisiana. Please give complete personal and professional data, salary requirements, approximate date of availability in first letter. All replies confidential. Address Box 6-8.

### SITUATIONS WANTED

#### A.I.Ch.E. Members

**Experience Wanted**—B.S.Ch.E. 1949. 25, married, two children. One year sugar factory control laboratory benchman. Desire varied experience with smaller young progressive company. Planning career in design and research. Prefer west of Mississippi River. Box 2-8.

**Industrial Research Group Leader**—Registered engineer. Twenty-two years' experience in guiding new projects from conception through final plant demonstration. Would prefer organizing permanent research group for medium size company. Box 3-8.

**Chemical Engineer**—3½ years' extensive experience in engineering development and plant operation, test work in heavy chemicals and electric furnace operation, electroplating, metal finishing and allied fields. Good appreciation of teamwork required between engineering, operating, maintenance and quality control. Desire responsible position in engineering, production or technical service. Box 7-8.

**Chemical Engineer**—B.Ch.E. from R.P.I., M.S.Ch.E. from Bucknell. One year teaching experience; one year industrial research experience. Desire position preferably research and development in Philadelphia Trenton area. Box 8-8.

**Licensed Chemical Engineer**—M.S. in Ch.E. Six years' diversified experience in research, pilot plant, and production. Proven ability. Desire responsible position in process development, technical service, or production. Box 9-8.

**Process and Project Engineer**—B.S.Ch.E. 1941. Tau Beta Pi, veteran, married, age 30. 3½ years design and supervision of design of petroleum and chemical plants and equipment. 3 years research and development and pilot plant work. Box 10-8.

#### Nonmembers

**Chemical Engineer**—B.S. 1947, M.S. 1950, 28, veteran, married. Three years of development of research in rubber field. Desire technical position with future. Box 11-8.

William L. Rodich has been appointed manufacturing manager of the chemicals division of General Electric's chemical department. In this capacity he succeeds Paul Preston who was recently elevated to the position of manufacturing manager of the chemical department.

Bradley Dewey, president of Dewey and Almy Chemical Co., Cambridge, Mass., was the opening speaker on a symposium of Science and Society delivered recently before a Notre Dame audience. Mr. Dewey is chairman of the Notre Dame advisory council for science and engineering and was also rubber director during World War II.

Joseph Finke, formerly engineer in rotating assignments with the General Electric Co., Schenectady, N. Y., is now associated with the North American Aviation, Inc., in the atomic energy research department, Downey, Calif.

William E. Lacy formerly with J. P. Pritchard & Co., Kansas City, Kan., as job engineer, is now regional engineer with Black Sivalis & Bryson.

W. K. Fitch recently resigned his position in the research division of the Chicopee (Mass.) Manufacturing Corp. to accept the position of senior engineer (chemical) in the manufacturing engineering department of Bigelow-Sanford Carpet Co., Inc. He is located at the Thompsonville (Conn.) plant and is engaged in the study of manufacturing problems and the design of process equipment.

Earl A. Peterson is now associated with the engineering staff of the Visking Corp., Chicago. Prior to his new position Mr. Peterson was for many years supervising chemical engineer in the chemical products department of The Sherwin-Williams Co., Chicago. He received a B.S. in chemical engineering (1937) from Iowa State College.

Kirpal Singh Gill, formerly associated with Northwestern University, Evanston, Ill., as research associate, is now located in East Punjab, India, at V. and P. O. Nathuwalla Jadid, Tehsil Moga, District Ferozepore.

Ben K. Pospishil, has been transferred by the Koppers Co., Inc., to its research department in Kearny, N. J. He was formerly in the research division at Pittsburgh, Pa.

Marion P. Lelong, formerly foreman, deodorizer department, Procter & Gamble Co., has accepted an appointment as Fellow to the Mellon Institute of Industrial Research, Pittsburgh, Pa.



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## LOCAL SECTION NEWS

(Continued from page 31)

### COLUMBIA VALLEY

Manson Benedict, director of process development for Hydrocarbon Research, Inc., was the guest speaker at the June 22 meeting. He spoke on "Diffusion Separation Methods," a relatively new field in chemical separation technology. Dr. Benedict discussed four types of diffusion processes: mass, thermal, and gaseous diffusion, and permeation through plastic films.

At a short business meeting preceding the talk, W. O. Switzer, chairman of the education committee, reported the successful completion of the review course designed for chemical engineers preparing for professional license examinations.

Reported by George Sege

### BOSTON ICHTHYOLOGISTS

The last meeting of the Ichthyologists for this year enjoyed Prof. Walter G. Whitman's talk, "International Political Significance of World Liquid Fuel Supplies." Statistics on world oil production and proved reserves were interpreted in light of the world political situation.

At this meeting officers for the coming year were elected as follows:

Chairman—A. W. Fisher, A. D. Little, Inc.

Vice-Chmn.—C. A. Stokes, G. L. Cabot, Inc.

Sec. and Asst. Treas.—H. Avery, G. L. Cabot, Inc.

Treas.—P. M. Rinaldo, Dewey & Almy Chemical Co.

Reported by Henry Avery

### WESTERN NEW YORK

This section held its Annual Ladies' Night meeting, May 25, at the Red Coach Inn, Niagara Falls, N. Y. Approximately 70 members, ladies, and guests were in attendance.

Dr. Warren L. McCabe, President, A. I. Ch. E., gave a talk on "Building Materials—Their Development, Manufacture, and Marketing."

Reported by Earl C. Mirus

### KNOXVILLE-OAK RIDGE

A seminar was held June 13 on "Diffusional Aspects of Solvent Extraction." The discussion was led by Dr. F. P. Pike, professor of chemical engineering from North Carolina State.

At a previous meeting in Oak Ridge motion pictures of the physical action which takes place on a bubble-cap tray under varying flow conditions were shown. The film was introduced by W. B. Leavitt of the C. F. Braun Co.

Reported by F. S. Chance, Jr.

## D. E. HOLCOMB



Dysart E. Holcomb, formerly with the research and development department of the Sinclair Refining Co., has accepted the position of dean of engineering at Texas Technological College, Lubbock, Tex. He received a B.S. degree in chemical engineering from Texas Tech in 1937, and later did graduate work at the University of Michigan, where he received a Ph.D. degree in 1941. From 1941-46, Dr. Holcomb was associated with Universal Oil Products Co., Chicago. In 1946 he became associate professor of chemical engineering at Purdue University, and remained there until 1949, when he accepted the post with Sinclair.

John W. Cross, process engineer with Monsanto Chemical Co.'s Merrimac division, has been appointed process engineering group leader. Mr. Cross graduated from the University of Pennsylvania with a B.S. in chemical engineering in 1942 going to Monsanto in the same year as a research chemist. He joined the process engineering group in August, 1947.

## Necrology

### W. C. BAINBRIDGE

William C. Bainbridge, technical director of H. Kohnstamm & Co., Brooklyn, N. Y., died July 6. He was associated with Kohnstamm, manufacturers of anilines and dry colors since 1906 when he was appointed assistant chemist. For the next several years he was engaged in laboratory research work that consisted of the isolation and identification of aniline coloring matters, production and purification of many of the intermediates and their resulting dye stuffs, and the design of suitable apparatus for duplication of these later methods on a commercial scale. Later he was made assistant manager of the aniline color department. Mr. Bainbridge was a graduate of Polytechnic Institute of Brooklyn where he received a B.S. degree. He was the author of many scientific articles and held membership in several professional societies.

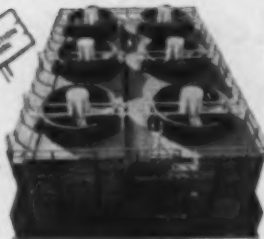


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Many stills, dryers, evaporators, crystallizers and other processing vessels are operating at vacua limited by the vapor pressure of the condensate. This means on the average an absolute pressure of about 2.0" Hg. Most owners of such equipment do not realize how practical and economical it is to put a Booster Evaporator in the line between the vessel and the condenser and maintain an absolute pressure of 0.5", 0.25" or even lower. The benefits of this higher vacuum in improving quality and capacity are often very substantial.

The steam jet type of vacuum pump has continually gained in fa-

vor for high vacuum in industrial process work. The total absence of moving parts is a big advantage and means many years of service, with no maintenance cost. Available in single, two-, three-, four- and five-stage units for vacuum from a few inches up to a small fraction of 1 m.m. Hg. absolute.

Croll-Reynolds have been specializing on this type of equipment for over 30 years, and have made thousands of separate installations. Their engineers have extensive experience in applying it to numerous different processes, and are available for consultation without obligation. Literature is also available on request.



## CROLL-REYNOLDS CO., INC.

17 JOHN STREET, NEW YORK 7, N. Y.

Chill-Vectors

Steam Jet Evaporators

Condensing Equipment

# Looking for piping...dependable quality? You'll get both from CRANE

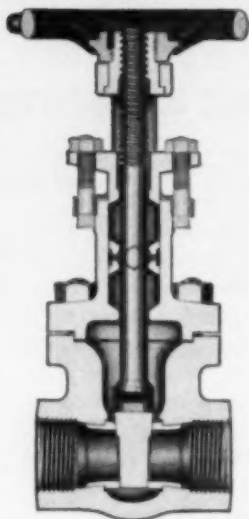
## FOR SAFE CONTROL OF HAZARDOUS FLUIDS

That's what you get with Crane Monel-Trimmed Steel Gate and Globe Valves. Unusually sturdy and rugged, they combine many features for safe control of highly toxic and corrosive fluids.

For example, note the specially designed, extra deep stuffing box. It's equipped with a packing spacer and plugged opening for proper lubrication of upper and lower packing. Note also the heavy cast steel body section... the husky bonnet flanges. Crane male and female bonnet joint design minimizes danger of leakage or blowout.

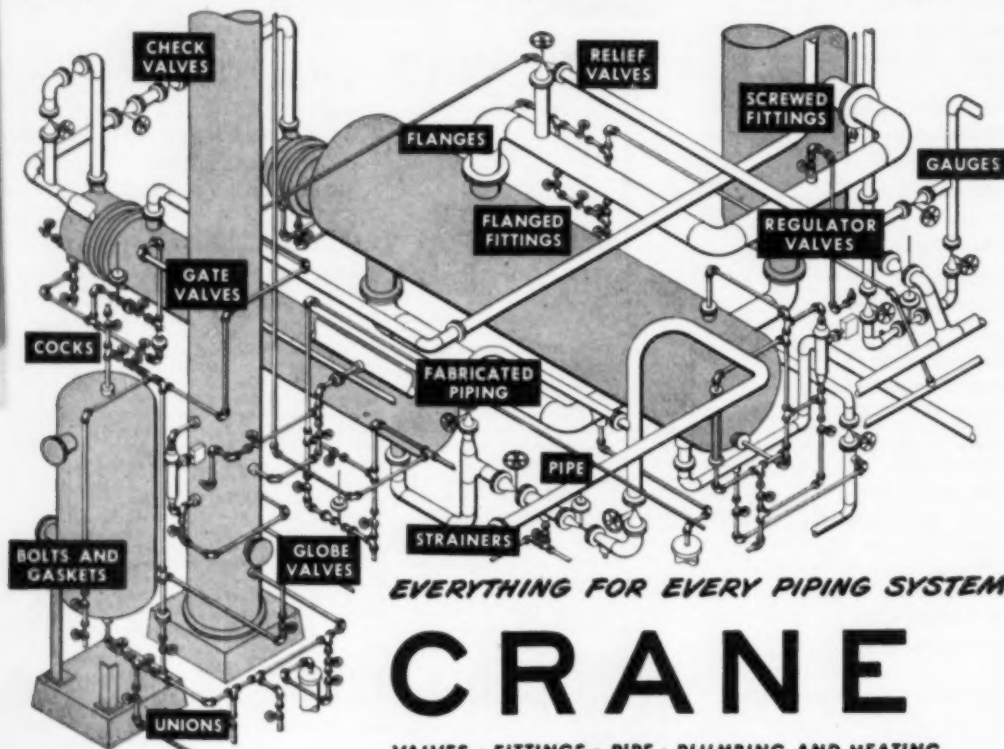
From end to end, these valves offer outstanding safety features. Threads in screwed end valves are extra long. Flanged end valves have large, raised male faces, finished with concentric grooves. See your No. 49 Crane Catalog, or send for folder AD-1622-A.

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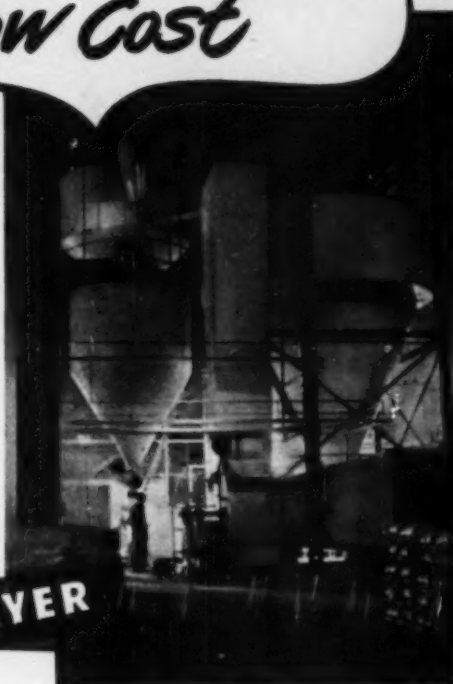
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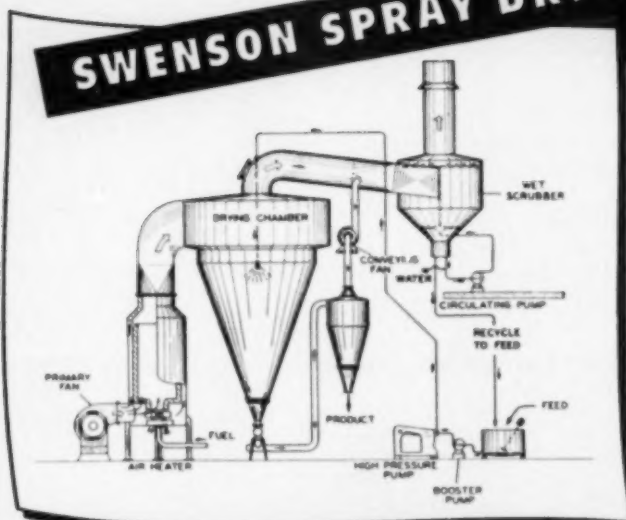
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Here is high-capacity spray-drying equipment that is especially suitable for handling heavy chemicals. It is direct fired, uses either oil or gas as fuel, and gives amazingly low-cost operation.

It is but one of many applications of Swenson\* Spray Dryers in the process industries. We will welcome an opportunity to assist you in adapting this equipment to your particular drying problems. Have you sent for our descriptive Bulletin D-105?



## SWENSON SPRAY DRYER



Direct-fired spray drying may be used for such materials as:

- Silica gel
- Kaolin clay
- Manganese sulfate
- Calcium carbonate
- Chrome sulfate
- Sodium phosphate

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\*Reg. U. S. Pat. Off.



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